Europa Lander

Science Payload

Draft Proposal Information Package

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CHANGE LOG

Date	Sections Changed	Reason for Change	Revision
02/14/2018	All	Initial Release	-
03/29/2018	All	Updates and corrections	Draft 13
04/23/2018	Table 3.2, Table 5.2	Updates and corrections	Draft 14
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1 INTRODUCTION

This Proposal Information Package (PIP) is provided with the National Aeronautics and Space Administration (NASA) Standalone Mission of Opportunity Notice (SALMON-2) Program Element Appendix (PEA) for instrument investigations for a Europa Lander Mission.

1.1 Proposal Information Package Purpose and Scope

The purpose of this document is to describe the Europa Lander mission concept, reference spacecraft, mission operations system, and Project policies in sufficient detail to allow teams to propose instruments that could be accommodated on a potential Europa lander and would conform to the mission concept and mission assurance constraints. This document is based on preliminary designs for the proposed Europa Lander mission.

The PIP describes the best estimate of the capabilities and resources of the reference spacecraft based on the current understanding of payload requirements. The Europa Lander instrument accommodations described in this document conform to the programmatic constraints specified in the PEA. Should there be any conflict between this PIP and the PEA, the PEA shall take precedence. The PIP contains the most current technical information and, in case of conflict, takes precedence over any other Europa Lander technical document in the PEA Program Library. The sections of the PIP are organized as follows:

Section 2	Mission Overview
Section 3	Payload Accommodations and Constraints
Section 4	Deliverables, Verification/Validation, and System Integration and Test
Section 5	Mission Scenarios
Section 6	Mission Operations System and Ground Data System
Section 7	Environmental Factors
Section 8	Safety and Mission Assurance
Section 9	Science Payload Management
Section 10	Instrument Accommodation Worksheet
Appendix A	Acronyms
Appendix B	References

1.2 Reference Documents

Table 1-1 summarizes documents, or specific portions thereof, that are an integral part of the PIP and applicable to the Europa Lander science instruments. These documents should be used to obtain more detailed information on various topics and are available in the PEA Program Library.

Table 1-1. Reference Documents

Reference Document	Document ID Number
General	
Europa Lander Science Definition Team Report	JPL D-97667
Europa Lander Environmental Requirements Document	JPL D-97633
Europa Lander Project Safety and Mission Assurance Plan	JPL D-97628
Europa Lander Parts Program Requirements	JPL D-97629
Europa Lander Materials and Processes Control Plan	JPL D-97664
Europa Lander Reliability Assurance Requirements	JPL D-97630
Europa Lander Project Safety Plan	JPL D-97631
Europa Lander Quality Assurance Plan	JPL D-97632
Radiation and Parts and Materials	
Assessment of Radiation Effects on Science and Engineering Detectors for the JEO Mission Study	JPL D-48256
Mitigating In-Space Charging – A Guideline	NASA-HDBK-4002A
Preferred Materials and Processes Selection List (PMPSL)	JPL D-92600
NASA and Program	
NASA Program and Project Management Processes and Requirements	NPR 7120.5E

2 MISSION OVERVIEW

The Europa Lander mission will launch in late 2025 and place a robotic Lander onto the surface of the Jovian moon Europa in the 2033 timeframe. The Lander will be equipped with an instrument suite designed to analyze samples acquired by the Lander's sampling system. The nominal Lander design is planned to operate for 20 Earth days before depleting its batteries.

The mission will be formulated and implemented by a joint Jet Propulsion Laboratory (JPL) and Applied Physics Laboratory (APL) Project team. The flight system is assumed to accommodate a payload of scientific instruments and a spacecraft that comprised of multiple flight elements that work in concert to execute various roles over the course of several distinct mission phases.

The mission is assumed to be a NASA NPR 7120.5E Category 1 mission and NASA NPR 8705.4 Class A risk category until official determination of project class and risk category is made and communicated to the Project by the NASA HQ Program Executive.

2.1 Mission Phases

2.1.1 Pre-Launch

The pre-launch phase covers all activity at Kennedy Space Center (KSC) prior to terminal countdown. This includes final spacecraft assembly, functional testing, encapsulation in the payload fairing, and configuration for launch.

2.1.2 Launch

Following the Europa Clipper mission's projected launch in 2022, the Europa Lander mission will launch on a separate launch vehicle no earlier than 2025 from Kennedy Space Center (KSC), Cape Canaveral, Florida, USA. Due to the large spacecraft mass at launch, the Space Launch System (SLS) launch vehicle is likely required to provide sufficient performance and is expected to be available by 2025.

2.1.3 Interplanetary Cruise

The baseline scenario launches the flight system from KSC and follows a ΔV-leveraged Earth Gravity Assist (ΔV-EGA) trajectory to Jupiter. ΔV-EGA launch opportunities to Jupiter repeat roughly every thirteen months with the synodic period between Jupiter and Earth. An example trajectory launches in November 2026, followed by a deep space maneuver (DSM), after which the spacecraft encounters Earth for a gravity assist and arrives at Jupiter in September 2031. Figure 2-1 shows this example trajectory.

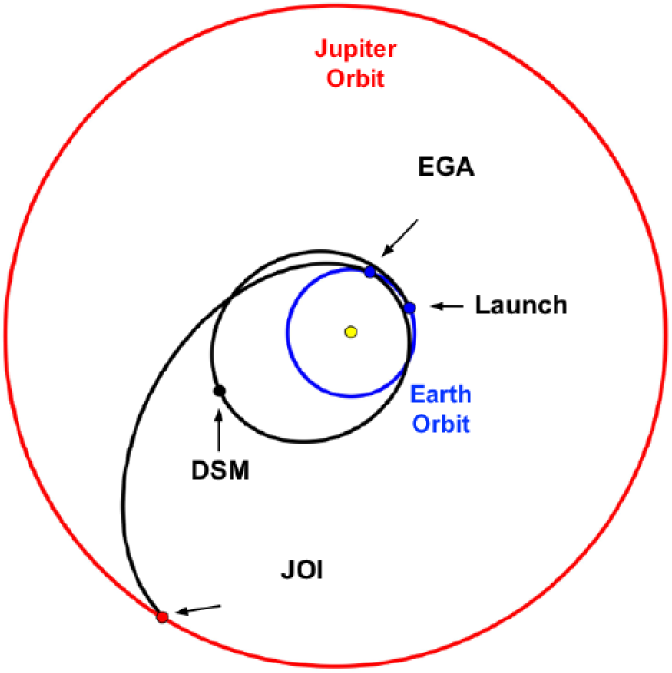

Figure 2-1. Example 2025 ΔV-EGA with 4.7 year transfer time

2.1.4 Jupiter Arrival and Transition to Europa

The tour trajectory begins with a Ganymede gravity-assist prior to the Jupiter orbit insertion (JOI) maneuver to establish a 200-day orbit. At apoapsis, a peri-jove raise (PJR) maneuver sets up the next gravity assist at Ganymede. This example tour trajectory is designed to reduce the spacecraft velocity relative to Europa, which minimizes the fuel requirements and the spacecraft's exposure to Jupiter's radiation. Consequently, the tour consists of a series of gravity assists at Callisto and Ganymede and the spacecraft encounters Europa at the very end of the tour, more than 30 months after JOI. Figure 2-2 shows a representative trajectory for the Jupiter tour of the mission [trajectory 12L4 in Campagnola et. al 2013].

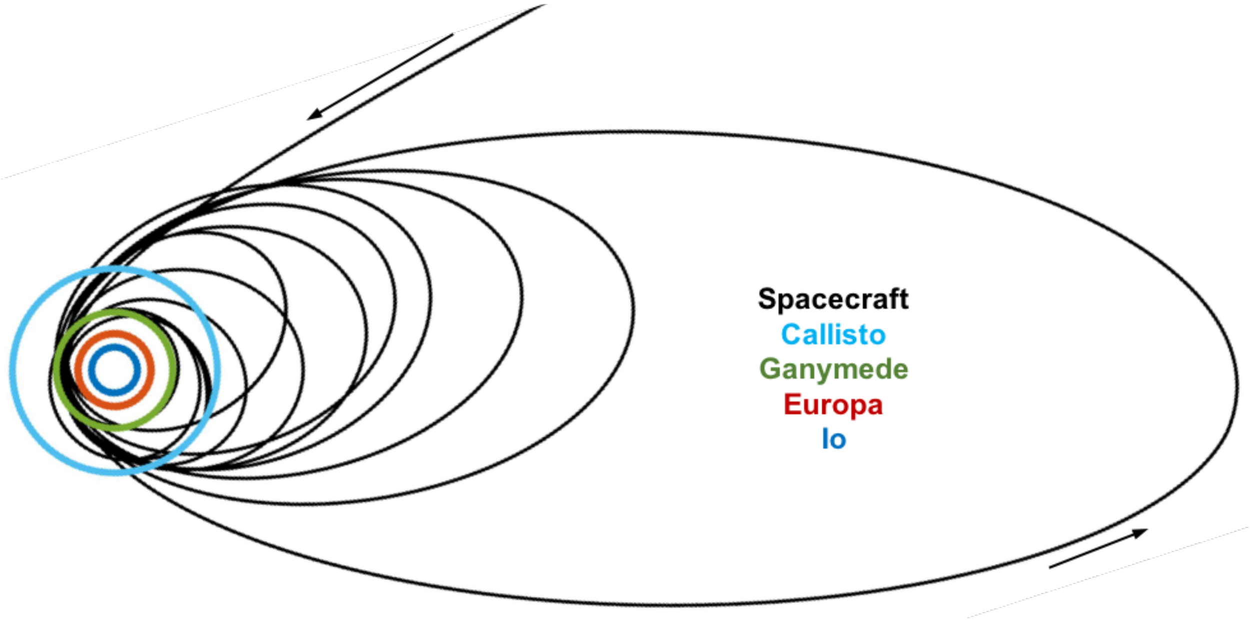

Figure 2-2. Example tour trajectory showing Jupiter arrival and transition to Europa

2.1.5 Europa Arrival and Landing

The first Europa gravity assist marks the beginning of the mission phase before landing, and the spacecraft is exposed to much higher daily radiation doses. The first Europa gravity assist is designed to insert the spacecraft into a Europa-resonant orbit and ΔV-leveraging maneuvers that further reduce the spacecraft's velocity relative to Europa [Campagnola & Russell 2010]. At the final Europa encounter, the spacecraft performs a Europa Orbit Insertion (EOI) maneuver to achieve a stable orbit. This orbit provides for delivery of the DOV (Deorbit Vehicle) to spacecraft separation as well as for safe disposal of the Carrier Stage (CS) to meet planetary protection requirements. This final part of the tour trajectory from first Europa flyby to landing takes approximately one month and sets up the Lander delivery to a 5-km periapsis altitude at a target state relative to the landing site (See Figure 2-3).

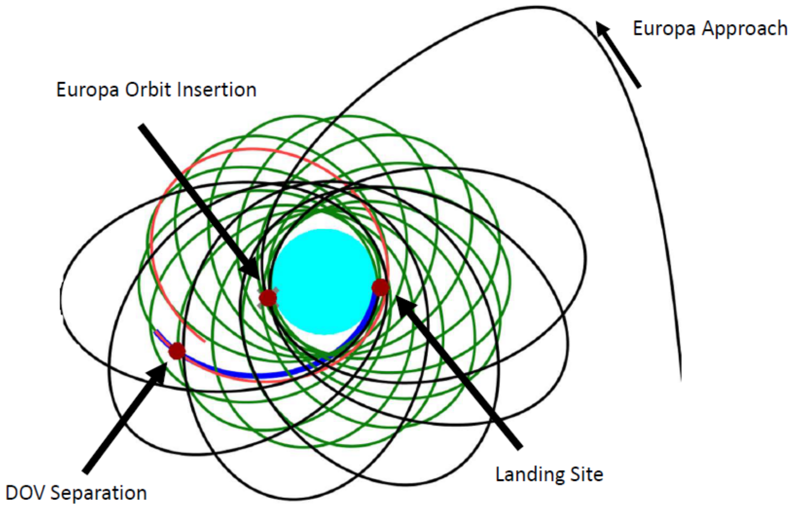

Figure 2-3. Example trajectory for Lander delivery orbit. Color Key: Black = Approach; Green = After Europa Orbit Insertion; Orange = Carrier Stage after DOV separation; Blue = DOV Deorbit, Descent and Landing

Shortly before landing, the Deorbit Vehicle spacecraft separates from the CS, followed by a maneuver by the Descent Stage to lower periapse for landing. The De-orbit, Descent, and Landing (DDL) will be completely autonomous due to the long light-time between Europa and Earth and the fast sequence of events during DDL. The Lander is assumed to use a solid rocket motor for de-orbiting and will rely on computer vision for Terrain-Relative Navigation (TRN) and hazard avoidance during its subsequent powered descent. In the last stage of landing, the Lander will be lowered on bridles from the descent stage in a sky crane configuration before final touchdown, after which the descent stage flies away and crash-lands at a safe distance from the Lander. The landing events are depicted in Figure 2-4.

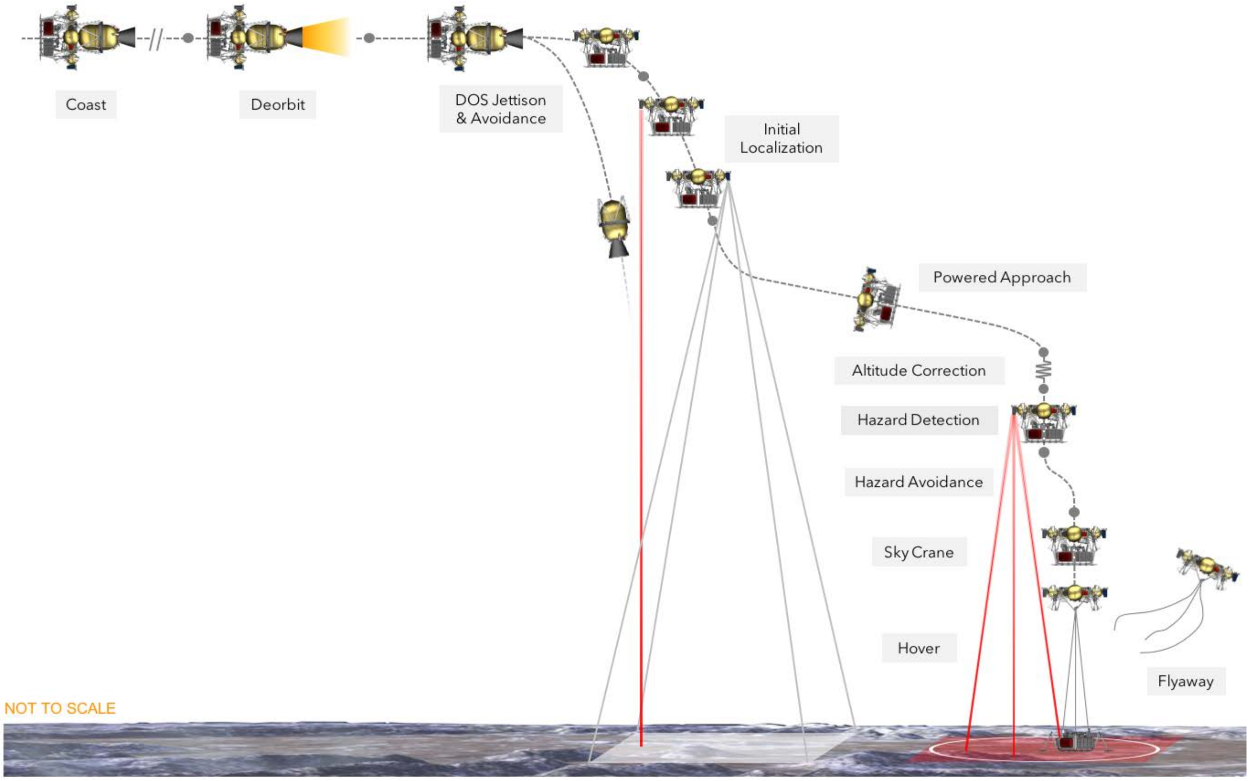

Figure 2-4. Notional DDL Sequence of Events.

The transition to the surface phase is the final portion of DDL and occurs immediately after touchdown when the Lander begins critical deployments and performs instrument aliveness tests. Critical deployments include deployment of the sampling system and the high gain antenna (HGA). The entire surface transition is performed autonomously, at the conclusion of which the Lander will be ready to acquire and analyze the first sample from the surface of Europa.

2.1.6 Surface Phase

The surface phase of the Europa Lander mission is dedicated to science activities. The surface phase is expected to last no more than 20 Earth days due to energy constraints. The Lander will complete a minimum of three sample acquisitions and the associated sample analyses. Additionally, monitoring and imaging instruments will collect data throughout the surface mission.

The communications architecture is Direct-To-Earth (DTE) between the Lander and the Deep Space Network (DSN). Europa's rotation period of ~ 3.55 Earth days results in the pattern alternating between ~ 1.5 Earth days of the Lander in view of Earth followed by ~ 2.0 Earth days of the Lander out of view of the Earth. The Surface Phase is organized into four activity type periods: Transition to surface (deployments, etc.); Checkout of spacecraft and instrument; Monitoring; and Sampling. During a monitoring period only environmental monitoring instruments are collecting data. A sampling period is a sequence of sampling and science activities that include the acquisition of the sample and the operation of the analytical science payloads. The sampling system and the analytical instrument may operate in parallel, e.g. instrument warmup and preparation steps during sample acquisition, or instrument #1 sample analysis initiating during sample transfer to instrument #2, etc. Further, monitoring instruments may operate in parallel with analytical instrument operations. The post-selection instrument accommodation activity will identify any conflicts between parallel operations and update the baseline scenario as needed.

The surface spacecraft is required to be significantly automated to ensure efficient use of the time on the surface. It will not be possible to rely on frequent ground-in-the-loop interactions for either nominal or minor anomaly scenarios. The combined spacecraft and instrument designs will need to support a degree of autonomous, automated, and coordinated behavior surpassing the automation demonstrated on Mars rovers.

2.1.7 Disposal/Disposition Phase

After releasing the DOV for DDL, the Carrier Stage disposal will remain in the delivery orbit, which was selected to meet planetary protection requirements. After the completion of the surface phase, the Lander system's exterior will be sterilized due to immersion in the radiation environment, and the interior will be sterilized using the terminal sterilization system.

2.2 Spacecraft

The spacecraft comprises four separate stages: the Carrier Stage (CS), the Deorbit Stage (DOS), the Descent Stage (DS), and the Lander. The stages are designed to work in concert to deliver the Lander to the surface of Europa once separated from the launch vehicle. An exploded view of the entire flight system is illustrated in Figure 2-5.

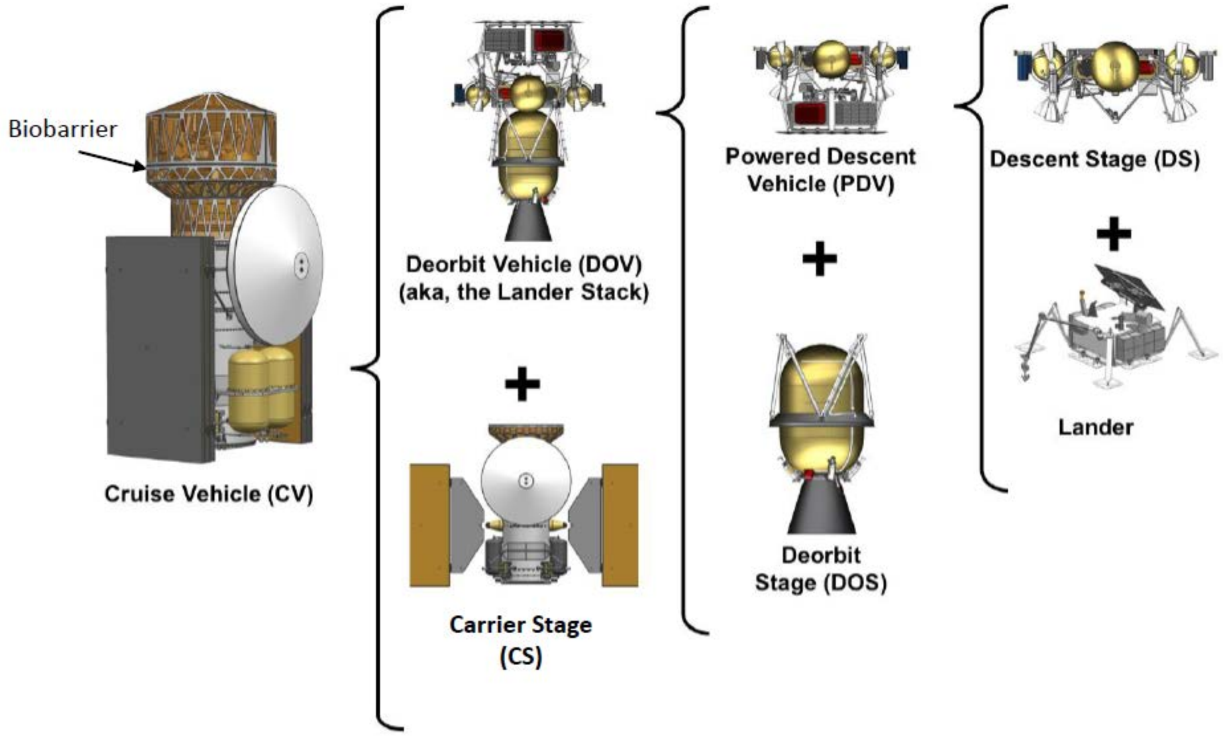

Figure 2-5. Europa Lander Flight System Configurations

Several factors levy requirements on the flight system and are described in further detail throughout this document. These include, but are not limited to, the propulsive needs in order for the CS to reach Europa, the Jovian radiation environment, eclipse and occultation considerations, the final distance from the sun, planetary protection and contamination control.

Each of the flight system stages and configurations are described below. Additionally, the sample acquisition system and payload, both of which will be accommodated by the flight system, are briefly introduced.

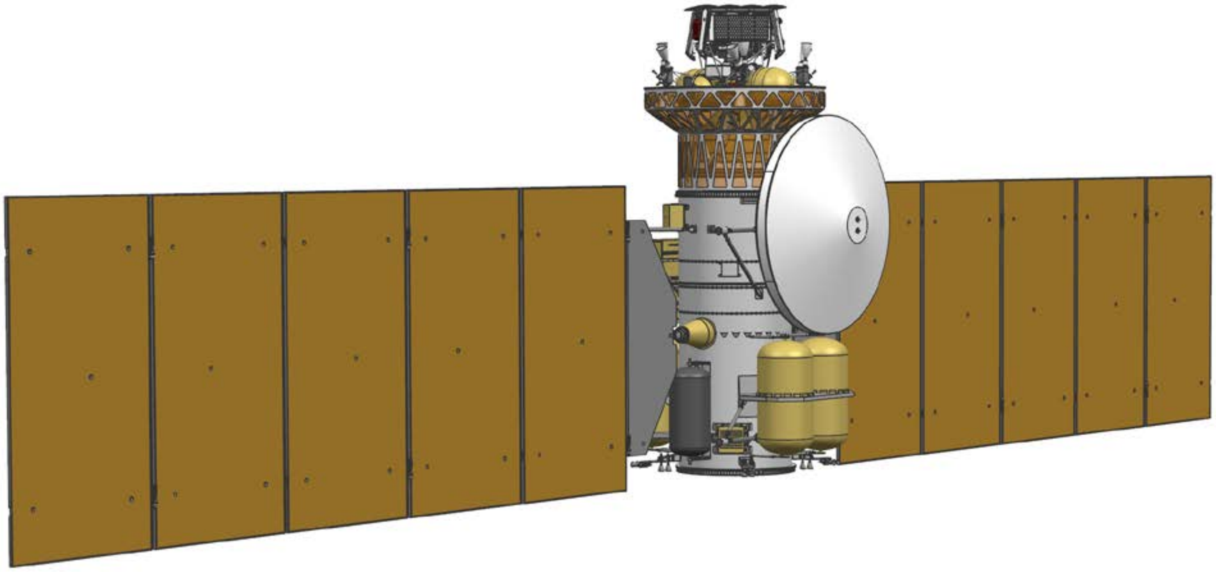

Figure 2-6. Cruise Vehicle (CV) Configuration

2.2.1 Cruise Vehicle (CV)

The Cruise Vehicle (CV) contains the DOV and the Carrier Stage (CS). In this configuration, the Deorbit Vehicle (DOV) is contained within a Bio-Barrier (as shown in the CV configuration in Figure 2-5) to protect from biological re-contamination during the final portion of integration, testing, launch, and early cruise. Prior to the first deep space maneuver, the Bio-Barrier will be jettisoned, exposing the Lander and other hardware (see Figure 2-6). The spacecraft remains in the Cruise Vehicle configuration until the CS separates from the DOV just prior to the DDL events.

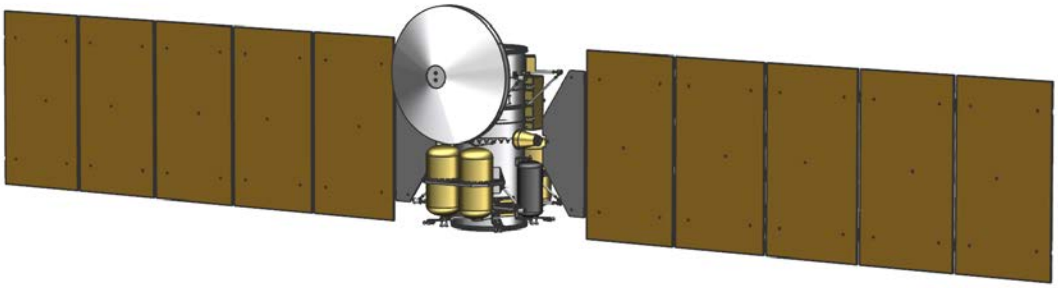

Figure 2-7. Carrier Stage (CS) Configuration

2.2.2 Carrier Stage (CS)

The solar-powered Carrier Stage (See Figure 2-7) is similar in architecture to the Europa Clipper spacecraft, but does not accommodate any scientific instruments itself. The purpose of the CS is to support the vehicle during Cruise, i.e., solar power collection, communication with Earth, and Trajectory Correction Maneuvers (TCMs). After separation from the DOV, the mission of the Carrier Stage is complete.

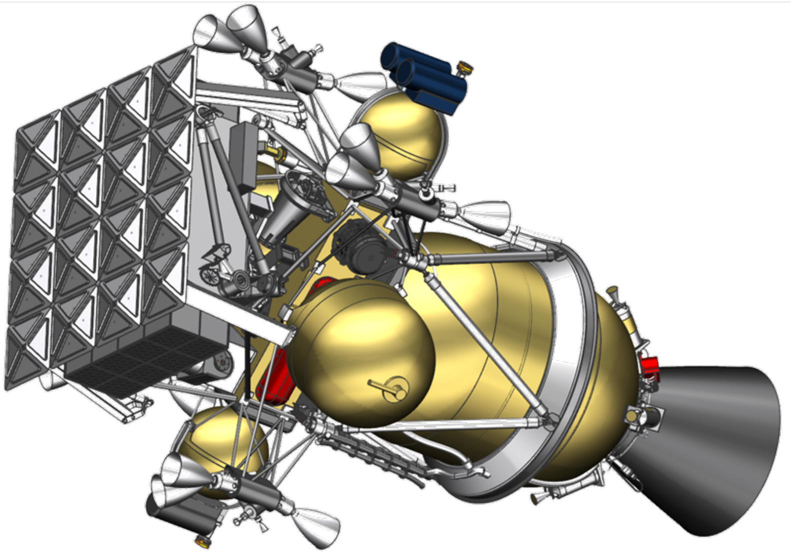

Figure 2-8. Deorbit Vehicle (DOV) Configuration

2.2.3 Deorbit Vehicle (DOV)

The De-Orbit Vehicle (DOV) configuration (Figure 2-8) contains the Powered Descent Vehicle (PDV), and the Deorbit Stage. In this configuration, the spacecraft performs a maneuver shortly after separation to lower periapse, and then fires the solid rocket motor to initiate DDL, as described in Section 2.1.5.

2.2.4 Deorbit Stage (DOS)

The Deorbit Stage (DOS) consists primarily of a large solid rocket motor (SRM), with additional interfaces and thermal protection hardware for the particular needs of this mission. The Deorbit Stage will provide the primary ΔV of the DDL phase over the course of a single burn. Attitude and guidance during the burn will be controlled by the Descent Stage. During this maneuver, some amount of burned and unburned solid rocket propellant (primarily ammonium perchlorate, aluminum and other additives) from the main motor, as well as smaller stage separation motors, may be deposited on exposed surfaces of the Lander and should be considered as a possible source of contamination (see Section 7).

2.2.5 Powered Descent Vehicle (PDV) and Descent Stage (DS)

The Powered Descent Vehicle (PDV) contains two elements: The Lander and the Descent Stage (DS). After completion of the solid rocket burn, the Powered Descent Vehicle (PDV) separates from the Deorbit stage. In this configuration, the Descent Stage (DS) employs a hydrazine monopropellant propulsion system, imaging, and lidar to guide the PDV to a safe landing site. The vehicle employs a “sky crane” landing system functionally similar to the one used on the Mars Science Laboratory mission. Once in close proximity of the surface of Europa, the PDV separates into DS and Lander. The DS (See Figure 2-9) lowers the Lander to the surface by means of a bridle while hovering above. Once the Lander touches down and is stable on the surface, the bridle separates from the Lander, and the DS conducts a fly-away maneuver to avoid impacting the landing site. During Descent and Landing, some amount of hydrazine monopropellant plume constituents (primarily nitrogen and water) will be deposited on the exposed surfaces of the Lander and the landing site (primarily nitrogen and water) and should be considered as a source of contamination (see Section 7).

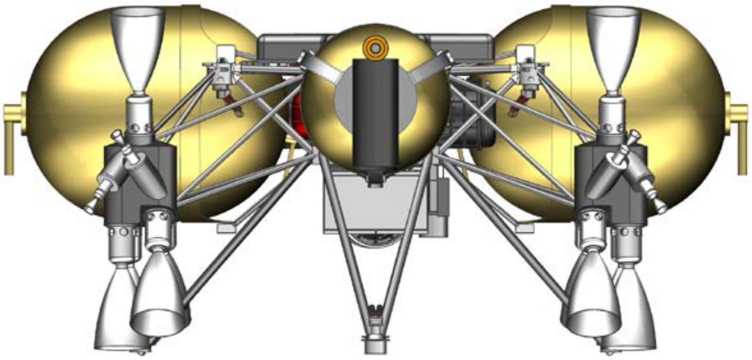

Figure 2-9. Descent Stage (DS) Configuration

2.2.6 Lander

The Lander is an integrated system that consists of the Lander flight system, the sampling system, and the payload system. This configuration is shown in Figure 2-10 and each component is described below.

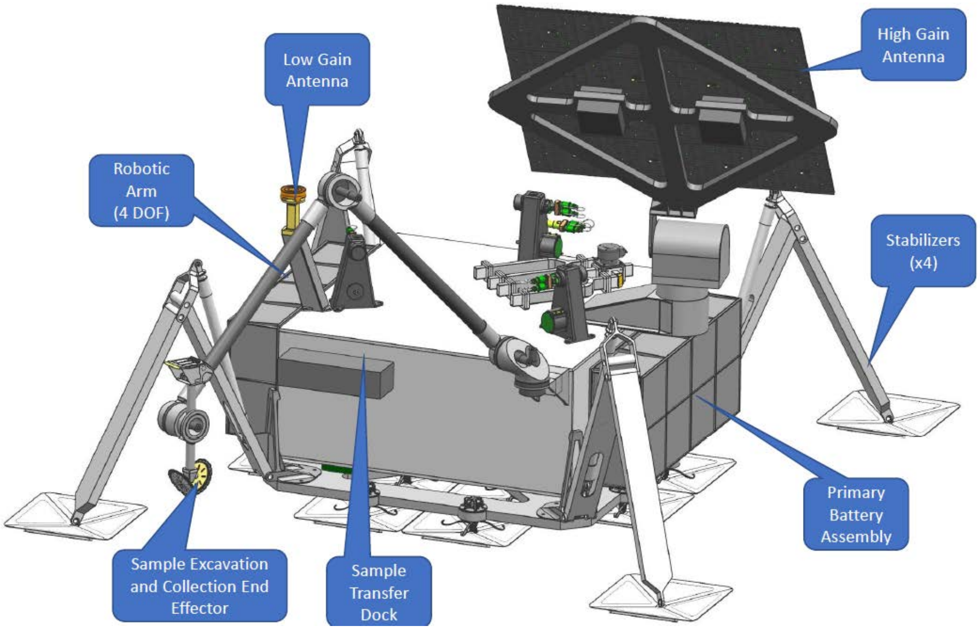

Figure 2-10. Lander Configuration

2.2.6.1 Lander System

The Lander System is responsible for conducting all science operations while the Lander is functioning on the surface of Europa. In order to acquire and analyze Europa surface samples, the Lander segment must be designed to survive the Europa surface conditions.

Unlike recent surface missions to Mars, the Europa Lander will not rely on solar power (Mars Phoenix Lander, Mars Exploration Rovers) or a multi-mission radioactive thermal generator (Mars Science Laboratory) to generate power. The Lander's planned 20 Earth day operational life will use energy supplied by primary batteries. The system must therefore utilize automation to be efficient in the use of time.

The Lander houses an avionics system that is responsible for all command and data handling and also interfacing with each of the science instruments. The data generated by the instruments are stored in non-volatile memory (NVM), which is also part of the avionics system. The telecommunication is via a Direct-To-Earth (DTE) link. Once the data are available to downlink, and Earth is within view, the Lander telecom system will transmit data to the Earth.

Any instrument component located outside of the Lander body (e.g., CRSI camera heads), will need to be provided adequate radiation shielding within the instrument design since such component will not be able to benefit from the vault surrounding the Lander body. The sensitive avionics, telecom electronics, analytical, and monitoring instruments reside within a spacecraft vault. The radiation environment experienced inside any given instrument is determined by the shielding inherent in the instrument's mechanical design (e.g., enclosure), shielding provided by neighboring hardware in the vault, and the vault itself. This vault will be designed such that the TID within an instrument does not exceed 150 krad, and therefore instrument electronics components that tolerate 300 krad will be adequate to meet the required Radiation Design Factor (RDF) of 2.0. For the purposes of sizing the vault prior to instrument selection, simple assumptions have been made regarding instrument volumes and inherent self-shielding characteristics. Proposers are encouraged to be specific in their proposals regarding enclosure material and thicknesses, large internal brackets, etc. to refine the assumptions on which vault sizing rely. If a proposer’s design uses components (e.g., detectors, optical elements, etc.) that cannot tolerate 300 krad, and/or associated flux, then the Proposer is responsible for identifying such parts and providing spot-shielding within the instrument design as required. Mass for spot shielding shall be bookkept within the specific payload’s MEL. Radiation is further discussed in Section 7.

2.2.6.2 Sampling System

The Europa Lander will provide a sampling system as a spacecraft capability. The sampling system will be critical to the scientific objectives of the mission that require evaluation of the surface material. The sampling system is responsible for excavation, collection, and presentation (or transfer) of samples to scientific instruments for observation. The sampling system is also responsible for the integrity of the sample from excavation until physical transfer into any instrument in the vault or delivery to the vault. The principal elements of the sampling system include a Lander-mounted robotic arm, a tool for sample excavation, a sample collection device, a sample transfer dock, and a mechanism for moving, presenting, and transferring samples to the instruments.

Proposed instruments that need to observe, evaluate, and/or handle surface samples in close proximity will have the samples presented or transferred to them by the sampling system. Provisions for mounting instruments to the Robotic Arm are not included in the current Lander design since such an approach has historically resulted severe accommodation impacts to mass, volume, etc. Instrument teams that wish to propose placing an instrument on the Robotic Arm should provide sufficient technical detail to enable an accommodation assessment, and accommodation resources will be counted against the overall payload allocation. The sampling system is described in further detail in Section 3.4.

2.2.6.3 State of Sample Delivered to Payloads

As stated in the Europa Lander SDT Report (Section 4.1.2), the Europan material that is sampled may range from predominantly water-ice, to salt-dominated, to other surface composition types (e.g., organic "tholins"). The sampling system will deliver to the payload a sample consisting of a heterogeneous mix of chip sizes. Sampling-system-induced modifications to sample properties will be constrained to those listed in Table 3-5, notably a limit to temperature experienced by the sample to be < 150K (or 10K above local Europa surface temperature, if greater).

If the measurement technique of an instrument requires further processing of a sample (e.g., melting, desiccation, filtering, concentration, etc.), such functions are to be designed into the Instrument, described in the proposal, and accounted for in Instrument resource estimates (mass, energy, analysis timeline, instrument cost, etc.).

2.2.6.4 Payload System

Spacecraft performance characteristics may change in substantial ways before the final design is determined. However, resources and interfaces provided to the payloads described will be managed by establishing and utilizing appropriate margins. The instruments should be compatible with spacecraft, trajectories, mission scenario concepts, and launch vehicle types described in this section.

2.2.7 Lander Coordinate System

The coordinate system for the Lander is defined at its separation location from the Descent Stage. The orientation of the coordinate system of the Lander aligns with the CS to Launch Vehicle coordinate system varying in z-axis offset. The Lander’s coordinate system is shown in Figure

2-11, wherein the origin is at the center of the top deck, Z points down, and X and Y axis point thru top deck corners.

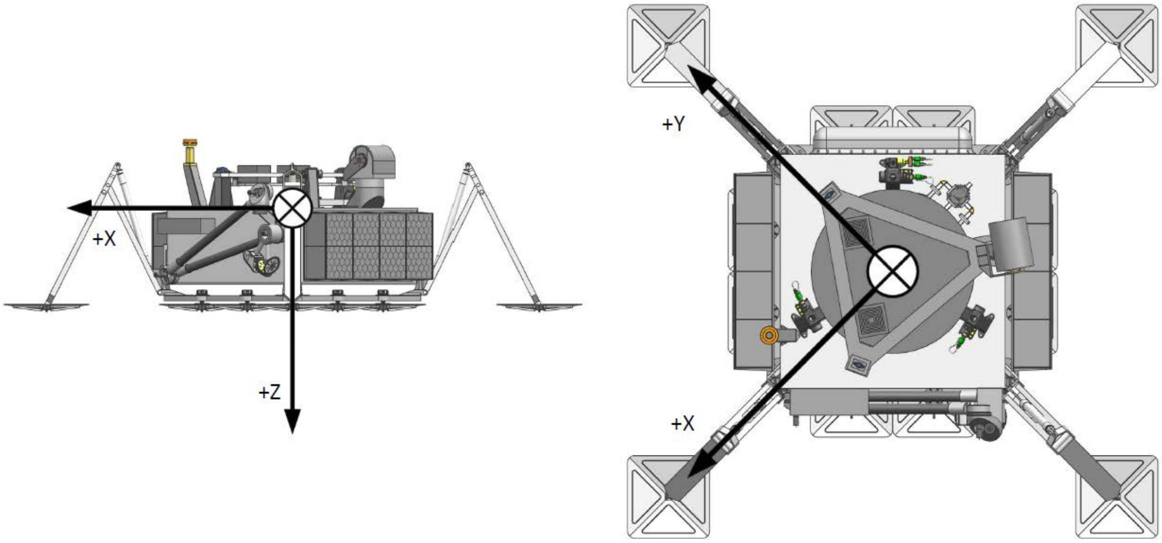

Figure 2-11. Lander Coordinate System

2.3 Mission System

The Europa Lander's mission system is comprised of the Mission Operations System (MOS) and the Ground Data System (GDS). The MOS comprises the people and procedures required to operate the spacecraft throughout all mission phases. The GDS consists of the hardware, software, facilities, and infrastructure used by the MOS. The mission system is described in detail in Section 6.

3 PAYLOAD ACCOMMODATION AND CONSTRAINTS

Accommodations described here are for a reference spacecraft concept that supports a notional payload package that meets the science objectives described in the PEA. As such, spacecraft performance characteristics may change in substantial ways before the design is finalized. Instruments should be compatible with spacecraft, trajectories, mission scenario concepts, and launch vehicle types described in Section 2.

3.1 Payload Accommodation Overview

Table 3-1 summarizes the locus of responsibility for various aspects of instrument accommodation. Subsequent paragraphs in the section describe each topic in more detail. Table 3-2 shows the not-to-exceed mass, volume, energy, and data allocations for the full integrated payload. Data return is limited by antenna size accommodation considerations on the Lander combined with earth-view constraints for the Direct to Earth mission design. The data allocation shown in the table reflects the payload portion of the overall data budget.

Table 3-1. Model Payload Accommodation Responsibilities

Item	Design and Implementation	Mass Allocation
Instrument covers: Imaging	Instrument	Instrument
Instrument covers: Vault instruments	Project	Project
Sun and stray light shade	Instrument	Instrument
Instrument Calibration Targets	Instrument	Instrument
Vault shielding (See Section 2.2.6.1)	Project	Project
Additional shielding (see Section 7.1)	Instrument	Instrument
Outside the vault shielding	Instrument	Instrument
Instrument chassis in vault	Instrument	Instrument
Mounting brackets/structures	Instrument	Instrument
Spacecraft-controlled Survival Heaters	Instrument	Instrument
Intra-instrument cabling, inside vault, If needed	Instrument	Instrument
Cabling from vault to external instrument (i.e., CRSI)	Project	Instrument (assume 2m length)
Compression	Instrument	N/A
Data buffering	Instrument (as needed)	N/A
Data storage	Instrument	N/A
Time reference broadcast	Project	N/A
Rate buffering	Instrument	N/A

Table 3-2. The entire proposed integrated payload should not exceed these resource envelopes.

Resource	Payload Not-to-Exceed Value
Mass (see Table 3-1)	32.7 Kg at selection (CBE+Uncertainty) (1)
Volume (See Figure 3-1)	34.5 L (internal and external to the vault)
Energy	1600 W-Hr total for all payloads; See Table 5-2
Science Data	600 Mbits total; See Table 5-2
Note (1): The Project holds payload mass reserves for use post-selection to solve accommodation and other issues in order to achieve a not-to-exceed total payload mass of 42.5kg at hardware delivery	

3.2 Payload Mass

The available mass for scientific instruments on the Europa Lander is tightly constrained, given the relatively large amount of ΔV required by this mission, as well as provisions for radiation shielding, sampling, electrical power, thermal control, and landing systems, which are all likely to scale with payload mass and volume. Due to this mass sensitivity, competitive instrument proposals should clearly assert their Maximum Expected Value (MEV), with an appropriate percentage of contingency applied to a justifiable Current Best Estimate (CBE). Contingency may vary depending on the maturity of the technology and risk for mass growth (e.g., from new developments, or modifications needed for the mission-specific environment, science goals, or spacecraft accommodations). Standard NASA definitions and equations for CBE, MEV, etc., can be found the SALMON-3 Announcement of Opportunity, Appendix B, Requirement B-28, available at https://nspires.nasaprs.com. Volumetric constraints and configuration are described in Section 3.2.1.

Table 3-3. Example Payload Mass Suballocations

Payload	Example Suballocation (kg)
Box A – Analytic 1 including all instrument-specific sample handling	16.4
Box B – Analytic 2 including all instrument-specific sample handling	5.4
Box C – Analytic 3 including all instrument-specific sample handling	5.4
Box D – Monitoring	1.2
Box E – CRSI Electronics	1.2
Box F-1 & F-2 (Combined Total) – CRSI Camera Heads including radiation shielding and cabling	3.1
Total Payload Allocation	32.7

These allocations should be considered an upper bound on the MEV of the respective instrument system. Beyond the core instrument components, each instrument system Master Equipment List (MEL) should include those items specified as instrument responsibilities in Table 3-1. These allocations are based on the model payload described in the Science Definition Team report (JPL D-97667).

3.3 Instrument Locations and Volumes

Section 2.2 describes the full spacecraft, and section 2.2.4 describes the Lander in particular, which is the only element of the mission that has allocated volumes for accommodation of instruments. The only available volume envelope external to the lander vault is on the high-gain antenna (HGA) for the Context Remote Sensing Instrument (CRSI) imaging system camera heads. The lander system is severely resource limited and is **not** designed to accommodate the following:

- Instruments that initially reside in the lander vault and then are deployed for operations after landing,

- Any instruments (other than the imaging system) that would require external locations or deployment external to the vault, including on the lander legs
- Instruments that are located on any other flight system element other than the lander.

Any proposal that requests locations outside of the volumes described in this section will need to provide adequate information to enable assessment of the accommodation impacts.

Figure 3-1 depicts the available volume on the lander for accommodation of the instrument payloads. Exceeding the allocated volumes for the instruments can have significant impacts to the flight system because the packaging and layout of the housed components is tightly coupled to the geometry of the vault. Because of the wall thickness necessary to provide adequate shielding to the contained electronics, the vault is one of the largest mass items on the lander. Tight and efficient packaging of the contained electronics as well as their interconnecting harness enables the lowest-mass lander to be delivered to the surface. Increases in lander mass have direct impacts on the propellant and structural requirements for the DS, DOS, and CS. As shown, individual payload envelopes have been defined for each of the specific payload elements. Dimensions for each of the discrete envelopes can be found in Figure 3-1. The represented locations are for reference only and can potentially change based on volumes, available panel surface area, and sample operations. The allocations for individual instruments are negotiable, but the total volume allocated to all payloads is unlikely to increase given the considerations described above. Mass and volume allocations must meet overall mass and volume constraints. Flexibility in enabling a more tightly packaged payload suite is desirable.

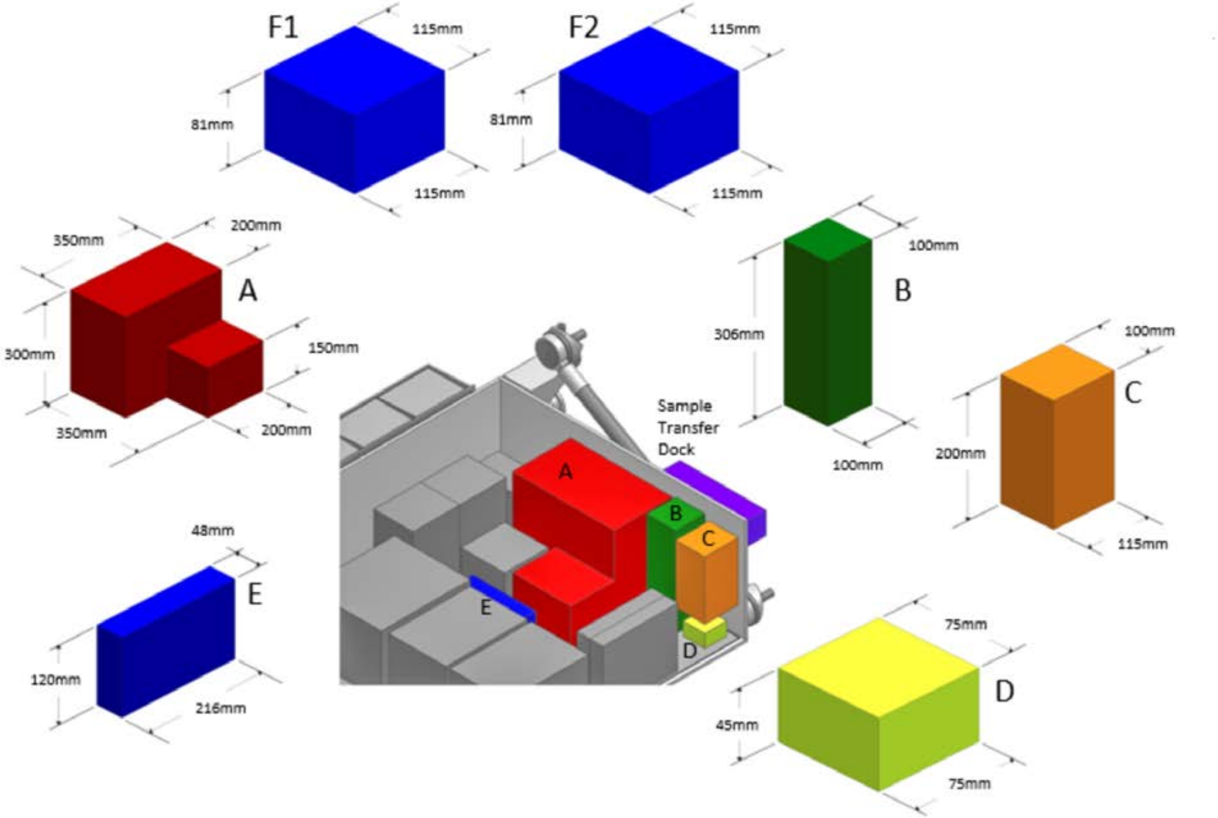

Figure 3-1. Instrument Locations and Volumes

3.3.1 Spacecraft Structural Interfaces/Mounting

Instruments that will be provided visual or physical access to the acquired surface sample will be mounted to the base panel of the vault utilizing a bolted interface on the inboard side of the panel. The three analytic instruments will each be provided ports in the vault wall located near the Sample Transfer Dock depicted in Figure 3-1. The final size and location of the ports will balance instrument needs with the incurred thermal losses and radiation protection necessary for the overall flight system. Covers for the instrument ports will be provided and actuated by the flight system. The Context Imaging Camera is mounted to the back of the High Gain Antenna in order to provide an articulating platform with a vantage point above the deck capable of viewing both the workspace and surrounding terrain in all directions. Cabling length from Camera Heads to Camera Electronics inside the vault should be assumed to be 2 meters in length. All instruments must be able to perform all operations over the range of Lander tilt up to 30 degrees relative to the gravity vector with cable mass accounted for by the instrument as per Table 1-1.

3.4 Considerations unique to the Context Remote Sensing Instrument

As described in the Science Definition Team Report Section 4.5.2, The CRSI will be used to image the surrounding landscape out to the horizon, generate Digital Elevation Maps of the sampling workspace, and identify features as small as 1mm. Further, the CRSI may be used to provide science-supporting engineering data such as images of sampling system placement, docking for sample transfer to instruments, etc. Note that the data volume associated with engineering use of the cameras is bookkept outside the Payload data volume allocation. Some engineering uses will require further image processing (e.g., generation of a Digital Elevation Map (DEM); any such processing and the associated algorithms, software, and resources is the responsibility of the Project.

Each camera of the CRSI has a minimum projected 15-degree rectangle (see Figure 3-2) such that images of a given sampling area within the workspace can be rapidly acquired with a single pointing location. The cameras will be articulated by the two-axis HGA gimbal which allows for 360-degree articulation about the vertical axis, and 180 degrees from the stowed orientation about the horizontal axis. Proposals for the CRSI must provide the specific field of view requirements for the imaging system as well as any stray light requirements and calibration-target placement requirements. Locations for these targets will be negotiated between the payload and the flight system. Volumes F1 and F2 in Figure 3-1 are intended for camera heads mounted to the back of the HGA.

Note that there may be periods when the workspace is not naturally illuminated—i.e., during the Europan night, or due to self-shadowing at high-latitude landing sites. Jovian-side landing sites would benefit from Jupiter-shine, but anti-Jovian landing sites would not. If there is a science requirement to operate the CSRI in these conditions, the CSRI would need to include any necessary illumination sources and account for the associated technical resources. Engineering use of the CRSI is not strictly required in un-illuminated conditions, but such a self-illumination capability in the CRSI would bring added operational robustness to engineering activities. Proposals should indicate what, if any, self-illumination capability is included in the payload design.

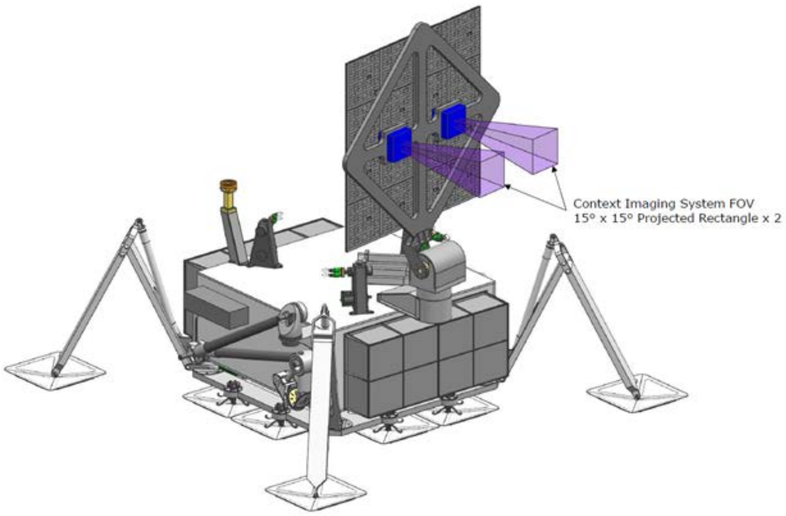

Figure 3-2. Fields of View

3.5 Considerations unique to the Geophysical Sounding System

The Geophysical Sounding System (GSS) is planned to be located within the vault, as shown in Figure 3-1. As such, the instrument will be subject to attenuation thru the Lander mechanical structure of Europan seismic events. In order to assess instrument accommodation, proposers are requested to specify (a) frequency range of interest, (b) directional axes of interest, and (c) acceptable level of signal attenuation due to Lander attenuation. Further, it is expected that some Lander activities (e.g., HGA and sampling system actuator motion) may generate acoustic noise in the frequency range of interest. Proposers are requested to specify threshold and baseline observation plans that enable the Geophysical Sounding System science investigation in enough detail to assess accommodation impacts to an overall integrated surface operations timeline.

3.6 Sampling System

This section describes the sampling system conceptual design and operations for the Europa Lander mission. This information includes requirements and constraints that will be imposed on instruments that intend to examine surface samples, as well as information regarding the interfaces between the sampling system and proposed instruments.

The sampling system will be critical to the scientific objectives of the mission. Although past interplanetary landed missions have successfully acquired and analyzed surface samples, there are unique and significant challenges with the Europa mission:

- Unknown terrain topography drives the sampling system design to be mechanically robust to a wide variety of surface features, shapes and roughness levels.
- Unknown surface properties (hardness, porosity, etc.), composition, and the potential for reactive constituents require that sample be maintained at cryogenic temperatures to preserve sample with respect to temperature and material phase prior to analysis by scientific instruments.
- Short mission duration (relative to past Mars surface sampling efforts) requires a higher level of autonomy in the system to drive down the number of commanding cycles required to acquire and deliver samples.

- Combination of the short mission duration and the long Europa day/night cycle require some of the sampling activities to be conducted without natural lighting (in the dark).

The initial concept for the sampling system is described in the following sections. As the design evolves and payload accommodation work begins, a tight coupling of the sampling system and the scientific payload will be required to ensure success of the mission.

3.6.1 Overview

The lander will provide a sampling system as a spacecraft capability (see Figure 3-3). The sampling system is responsible for excavation, collection, and transfer (or presentation) of samples to scientific instruments. The sampling system is also responsible for the integrity of the sample from excavation until physical transfer into an instrument. The principal elements of the sampling system, as summarized in Table 3-4 include a lander-mounted robotic arm, a tool for sample excavation, a sample collection device, a sample transfer dock, and a mechanism for transferring or presenting sample to instruments.

The robotic arm is not available for placement of scientific instruments in situ, and there will be no instruments or cameras mounted to the robotic arm. Proposed instruments that need to observe, evaluate, and/or handle surface samples in close proximity will have the samples presented or transferred to them by the sampling system. It is important to recognize that the physical configuration of the lander is highly constrained with multiple critical interfaces. First and foremost, the lander is designed to maximize landing safety, then optimized for sampling workspace accessibility and camera visibility within the kinematic constraints necessary to allow sample delivery back to the instruments. The lander physical configuration will evolve over time as the flight system design matures and accommodates the selected payload. The graphics in this section reflect the current design concept but should be considered notional.

Table 3-4. Sampling system elements.

Sampling System Element	Description
Robotic arm	Lander-mounted arm with end effectors for excavation and collection of surface samples.
Sample excavation tool	Primary tool mounted to the end of the robotic arm to be used for sample excavation.
Sample collection device	Primary device mounted to the end of the robotic arm to be used for collection of the excavated sample. This device is also responsible for any packaging of samples into containers to be presented/delivered to instruments.
Sample transfer dock	Hardware mounted on the lander where the robotic arm can dock to unload sample and/or sample containers from the sample collection device.
Sample transfer mechanism	Lander-mounted mechanism for handling sample and/or sample containers for presentation or transfer to scientific instruments.

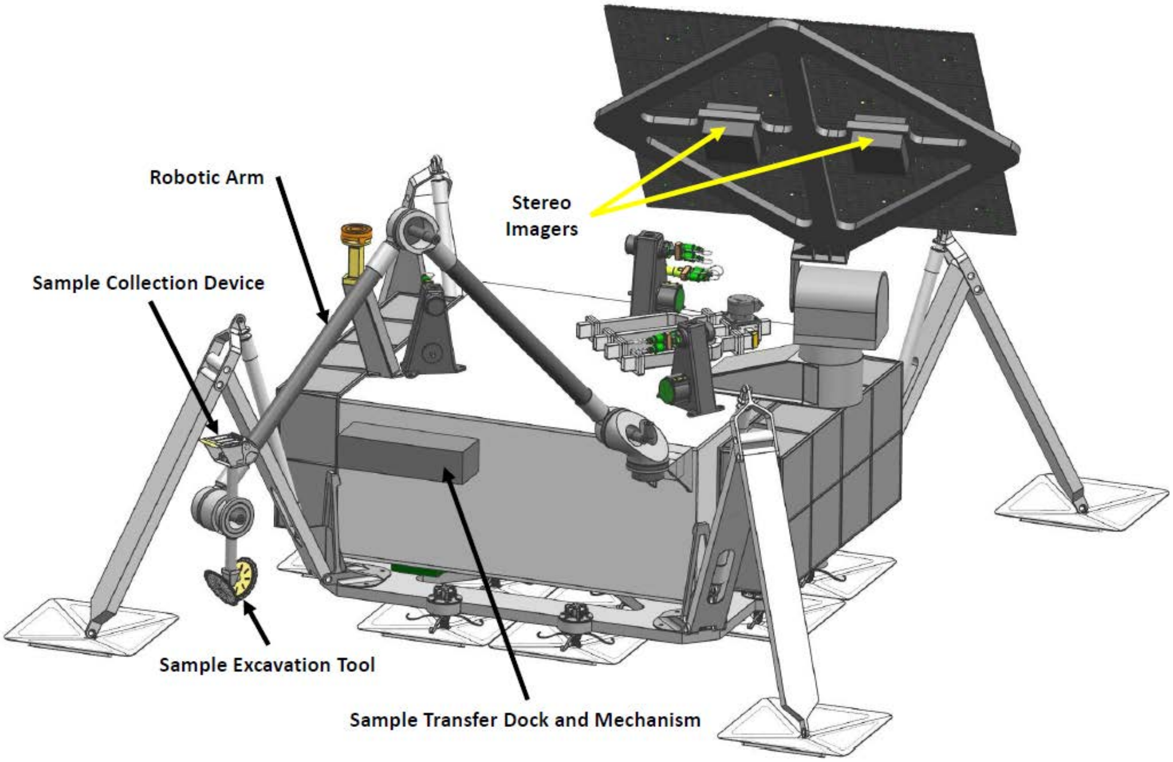

Figure 3-3. Overview of the sampling system hardware.

3.6.2 Sampling System Hardware

3.6.2.1 Robotic Arm

The sampling system will include a robotic arm (RA) for acquisition of surface samples from within a defined workspace. The RA will be approximately 1.6 m in length when fully extended. The arm will be used to position and manipulate two end effectors (also sometimes referred to as tools or devices). These tools will be responsible for excavating and collecting surface samples from a depth of at least 10 cm, and transferring them back to the lander for close observation by the science payload.

3.6.2.2 Sample Excavation Tool

The conceptual design for the sample excavation tool is a pair of counter-rotating saw blades that are swept across the surface and driven down to depth to provide access to samples with reduced radiation processing. Prototypes of this tool have demonstrated excavation of cryogenic water ice materials to depths greater than 10 cm in a laboratory setting. Saw tools have advantages that include effectiveness over a wide range of mechanical orientations, limited requirements for pre-loading on the cutting target, and are robust to variations in local surface topography.

3.6.2.3 Sample Collection Device

The sample collection device will be responsible for aggregating sample excavated from the surface at the target depth. It will also package the material into containers for presentation or transfer to the science instruments as required. When the sample has been collected from the target depth and packaged for transfer, it will be transferred back to the lander via the sample transfer dock. The initial concept for the collection device is based on the heritage Icy Soil Acquisition Device (ISAD) from the Phoenix mission. This device utilized the RASP (Rapid Acquisition Sampling Package) on the back of a scoop. The device uses a rotating rasp pressed against the bottom of the trench to penetrate into freshly exposed material, and collect the resulting particles kicked up by the rasp into an internal chamber and transfer the samples to scientific instruments. The RASP has proven capability to acquire material from hard surfaces with minimal thermal energy input. See Figure 3-4 for a view of the sample excavation tool and collection device. For the Europa lander mission, the ISAD will be modified to also package sample into instrument specific containers and/or prepare the sample to be directly plunged into an instrument (see later sections for more details).

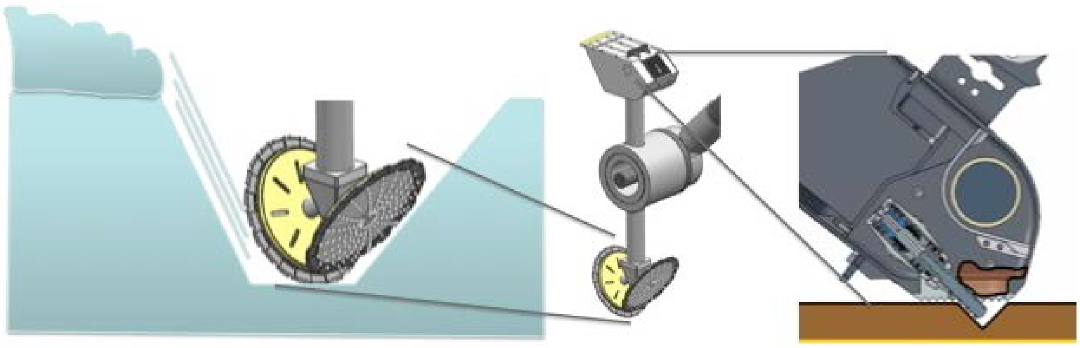

Figure 3-4. The sample excavation tool concept (counter-rotating saw) and the sample collection device concept (based on Phoenix heritage)

3.6.2.4 Sample Transfer Dock

The sample transfer dock will be mounted on the lander vault and used to accommodate docking of the robotic arm. Once the arm is docked to the lander, the sample collection device transfers sample and/or sample containers to the lander. The sample transfer dock will also serve as a reset location for the sample collection device to return it to the proper position for the next sample and as a storage area for any additional sample containers.

As part of instrument accommodation, the instrument teams and the Project will negotiate the specific sample transfer interface. Hardware that crosses this interface, e.g., containers, will be provided by the sampling system and all resources (mass, volume, etc.) for sample containers are bookkept within the sampling system's allocations.

3.6.2.5 Sample Transfer Mechanism

The sample transfer mechanism is the portion of the sampling system used for receiving sample from the sample collection device via the sample transfer dock and providing it to the instruments. The sample transfer mechanism will preserve sample integrity with respect to temperature and material phase while presenting it to instruments for observation or until transferring the sample into the vault for analysis.

3.6.3 Sampling Workspace

The surface area available to the lander for sampling operations, referred to as the sampling workspace, is affected by a variety of factors including the robotic arm length, end effector length, sampling depth requirement, physical configuration of the sampling system on the lander, CRSI field of view, CRSI articulation capabilities, stabilizer configuration, the lander orientation relative to the surface, and the surface topography itself. A notional workspace is shown in Figure 3-5 for a robotic arm of approximately 1.6 m in length. The sampling workspace will have a minimum required area of 1.8 m^2 for a nominal landing condition where the lander body is in full contact with a flat surface (i.e., zero terrain relief; zero tilt). The entirety of this required 1.8 m^2 area shall be reachable with the robotic arm for excavation to the target depth of 10 cm and visible to the CRSI for the production of digital elevation models (DEMs). The required workspace shall include no surface area within 10 cm of lander hardware such that the required area may be sampled all the way to the edge of the 1.8 m^2 workspace, forming the center point of a potential sample excavation.

The sampling workspace includes area to distribute additional materials either excavated but not collected ("tailings" from the sampling system), or collected but not delivered ("dumped" sample). These tailings and any dumped sample will be visible by the CRSI mounted to the lander. Figure 3-5 shows the potential sampling workspace available (shown in light blue) for a nominal landing condition relative to the required 1.8 m^2 (shown in darker blue). It is possible that two sides of the lander will be available for sampling, but this will depend on the final configuration of the lander and stabilizers after landing. The required sampling workspace of 1.8 m^2 on flat terrain will be provided on a single side of the lander closest to the sampling system.

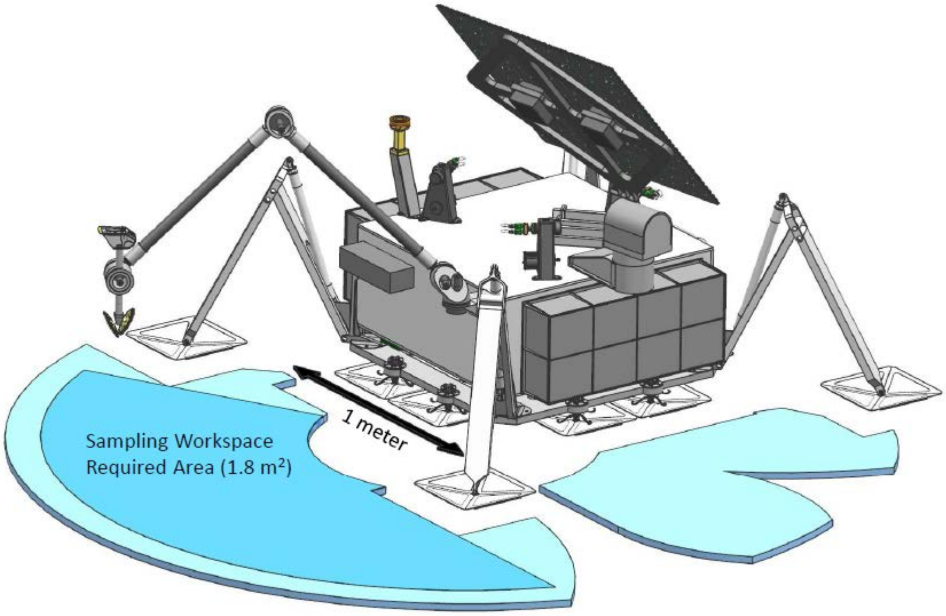

Figure 3-5. Sampling workspace on flat terrain showing required workspace size (dark blue region) relative to capability (light blue region).

3.6.3.1 Variation in the Sampling Workspace

The workspace ultimately available for sampling will not be determined until after landing on the surface of Europa. This is because there is no expectation that the Project will have sufficient understanding of the terrain at the scale required to select a landing site consistent with the required minimum sampling workspace size. The access to the surface for sampling is highly dependent on the surface topography and the final landing configuration and orientation. Figure 3-6 shows an example of a *favorable* lander configuration after touching down on a 25° slope (considered an off-nominal landing case). In this example, the minimum workspace requirement (1.8 m^2) will not be met on the primary side of the lander closest to the sampling system; however, with the addition of the secondary workspace on the side of the lander, the total available sampling workspace is greater than 1.8 m^2. It is important to note that although the vehicle will survive landing on slopes up to 25˚, and greater in some cases, there is no expectation that the lander will meet the sampling workspace requirement for all safe landings. For example, there are *unfavorable* landing configurations on a 25˚ slope similar to that shown in Figure 3-6 that will result in significantly less than 1.8 m^2 available for sampling. It is expected that the exact location of sampling within the available workspace will be selected to maximize the probability of successful sample acquisition.

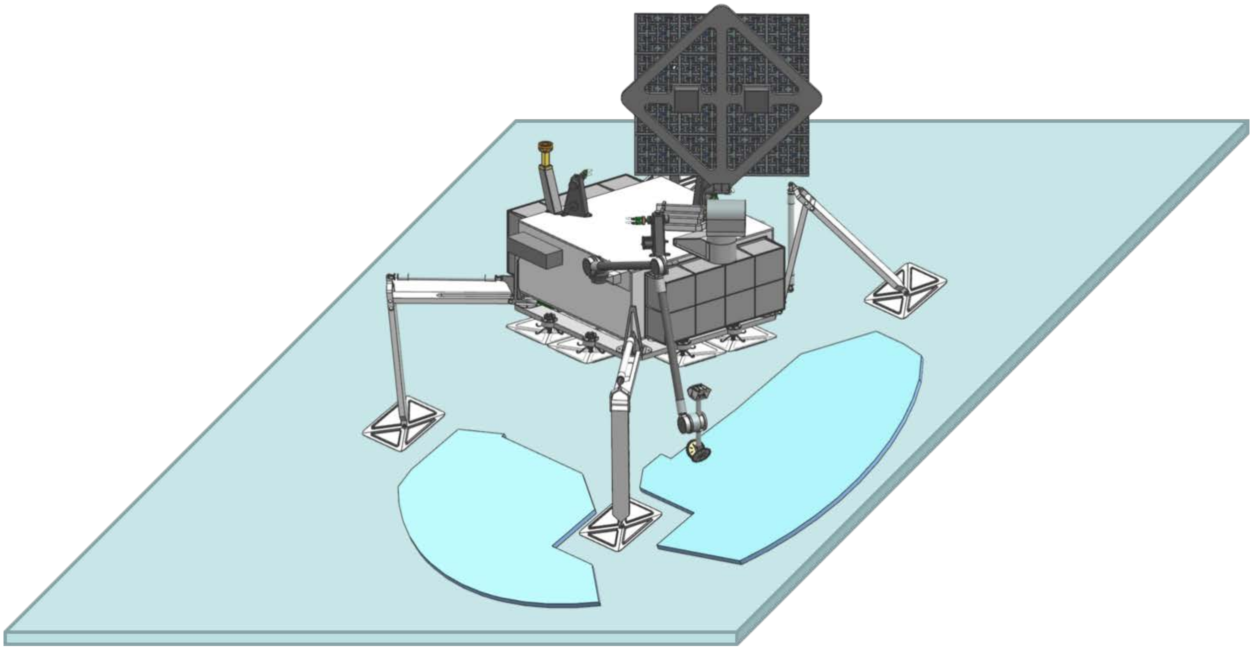

Figure 3-6. Off-nominal landing on uniform 25˚ slope shows that sampling workspace size (light blue) varies with landing configuration (compare to Figure 3-5). Favorable landing configurations may provide greater than required 1.8 m^2 while unfavorable landing configurations may provide less.

3.6.4 Characteristics of Delivered Samples

The Europa lander baseline mission includes the capability to acquire, present, and/or transfer samples to each science instrument requiring observation or manipulation of the surface material at close proximity. The sampling system is responsible for excavating, collecting and delivering these samples to the scientific payload, as well as maintaining the sample integrity with respect to temperature and material phase until final delivery to an instrument. After delivery of a sample to an instrument, it becomes the instrument's responsibility to maintain the mechanical, chemical, and thermal state of the sample as required by the particular scientific investigation. Any hardware mounted outside the vault (to address sample thermal control, for example) will be fully exposed to the radiation environment with no benefit from the vault, and should be described in enough detail to allow assessment of accommodation requirements.

The sampling system will deliver a sample at < 150 K to each instrument (or $< T_{\text{surface}} + 10$ K, whichever is higher). The sample will consist of a range of particle sizes and is expected to contain ice, salts, dust, and/or other insoluble material in proportions that are unknown *a priori*. Typical particle size distributions based on laboratory tests will be provided during development based on prototype sampling system hardware tests, with initial data provide after Instrument Selection and updated characterization data up through PDR. The maximum particle size is specified in Table 3-5. Given the inherently unknown nature of the Europan terrain at the actual landing site, however, sample handing within both the sampling system and the instrument will need to be robust to variation. The sampling system will be capable of acquiring samples from both consolidated (i.e., solid) and unconsolidated (i.e., loose) mixtures of cryogenic ice and non-ice materials. The science instruments will be provided separate samples from the same sampling site within the workspace.

Samples will be obtained and preserved with the characteristics outlined in Table 3-5. Sampling System Requirements and Sample Characteristics. The Sampling System will collect one sample from the target depth for a particular instrument, deliver that sample, and then return to the same location in the trench to collect a second sample for a different instrument. The sampling system is designed to compact the sample to reduce “fluff factor” (e.g., density decrease due to excavation activity), but the final mass of the sample within the delivered volume is not measured. The sampling system include sensors to confirm that at least half of the intended sample volume has been collected in order to prevent the situation of delivering an empty container and consequently wasting instrument resources and/or consumables. Proposals should specify and justify the minimum acceptable sample volume required for the measurement, the budget for expected internal sample volume losses between instrument inlet and final sample location for measurement, and the resulting minimum sample volume at the instrument inlet port. Proposers need to be aware that there will be some unavoidable mixing of materials from different depths during sampling; however, the sampling system requirement is that > 80% of material within a delivered sample will originate from >/= 10 cm depth. There is also a possibility of cross-contamination from sample to sample depending on the final design of the sample handling components, the surface material composition, and the ability to discard excess material between samples. Although no cross-contamination requirement is levied on the sampling system, the cross-contamination will be minimized where possible by design and/or cleaning techniques. Cross-contamination will also be characterized by test after the sampling system hardware is built.

Table 3-5. Sampling System Requirements and Sample Characteristics

Requirement on Delivered Sample	Baseline
Number of sampling locations within the workspace (i.e., number of trenches)	1
Number of samples delivered to each instrument	3
Minimum volume of each sample for each instrument	Proposers should specify requirement. Baseline assumption from SDT Report Model Payload is: 1. 1 cc for the Organic Compositional Analyzer 2. 1 cc for the Vibrational Spectrometer 3. 5 cc for the Microscope
Minimum target depth for delivered sample	>/= 10 cm (below horizontal surface)
Minimum fraction of delivered sample from target depth	80% (by volume)
Maximum fraction of sample-to-sample cross-contamination	No requirement but will characterize and minimize by design and operations
Maximum temperature of sample prior to presentation or delivery to science instrument	150 K (or $T_{surface}$ + 10 K, whichever is greater)
Maximum Particle Diameter	3 mm

3.6.5 Sampling System Operations

The lander flight computer will control placement of the arm and end effectors for sample acquisition and delivery. The sampling system will be capable of conducting a sampling cycle in a fully autonomous fashion with no input from ground operators, starting from a selected target sampling location and ending with sample delivery to all payloads. This autonomy capability is driven by both the short mission duration and the expected cadence of spacecraft commanding and data receipt. For more details on mission cadence, see Section 5.5.

Figure 3-7 presents a storyboard of operations for a single sampling cycle. After landing, the sampling system will be deployed from its launch stowed configuration with a set of one-time restraint releases and specialized moves to carefully unfurl the system. Once the sampling system is deployed and an initial sampling site is selected, excavation can begin. This will produce a trench and a tailings pile of material that has been removed from the newly excavated site. After excavation to the target depth is complete, the sample collection device will be placed into the trench to collect the amount of sample required for a particular instrument and package it into a container as required.Part of the packaging process is to sense and positively confirm the collection of sample prior to delivery. The robotic arm will then dock with the lander to transfer and deliver the containers to the instrument. Imaging will be interspersed with these activities for documentation as allowed by lighting conditions. The sampling system will repeatedly return to the bottom of the trench to collect at least 3 samples for each of the 3 instruments for a total of at least 9 samples for the mission.

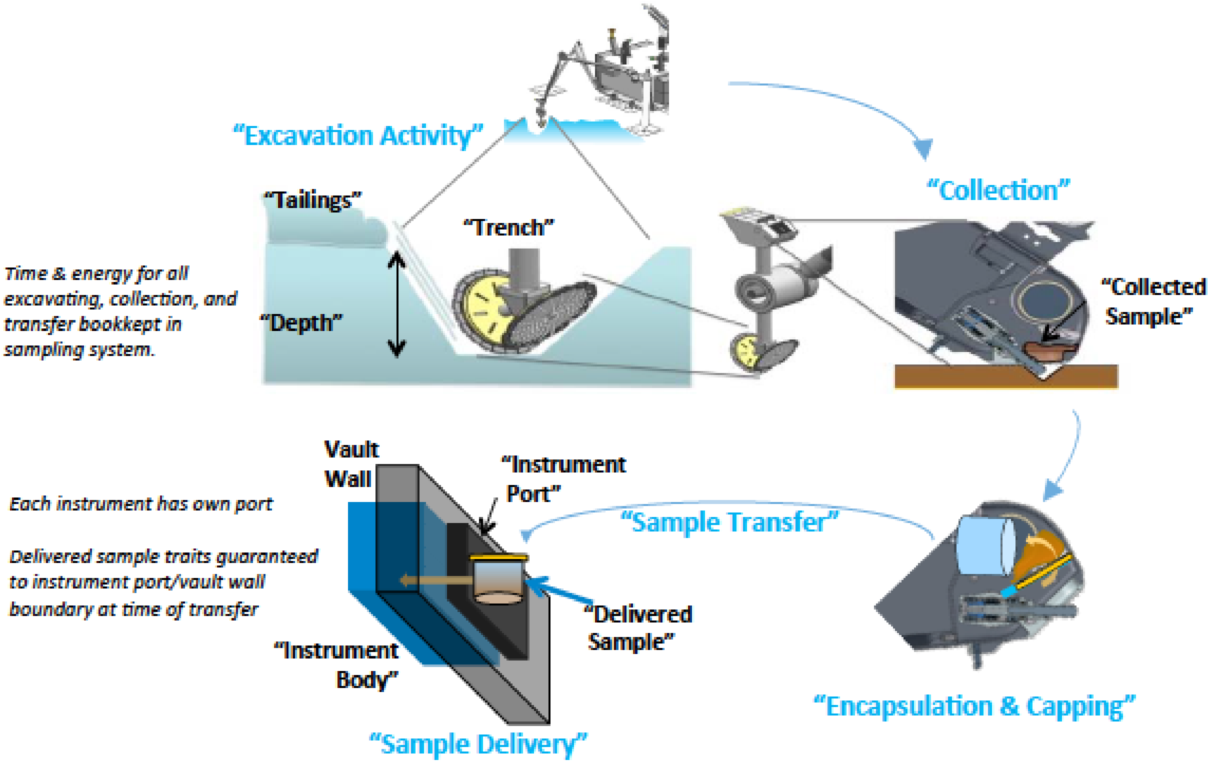

Figure 3-7. Sampling System Operational Storyboard

3.6.5.1 Lander Orientation

The sampling system will be able to perform all operations with lander orientations ranging from flat (gravity normal) up to 30-degree tilt from the gravity vector. All instruments must be able to perform all operations (observe, receive, handle, process, store, and analyze samples) over the same range of lander orientations.

3.6.5.2 Design Guidance regarding Gravity and Sampling Handling

Based on experience with prior planetary sampling missions the sampling system and instruments should not explicitly rely on gravity for motivating sample motion in any way. The reduced Europa gravity, large range of possible vehicle orientations and properties of potential materials to be sampled indicate that gravity-dependent sample motions and associated pre-launch verification would be problematic. Sample should be moved through the sampling chain with positive actuations at all points.

However, the design guidance is that gravity can be relied upon to ensure that sample will remain in a properly oriented open container (i.e. open side facing away from the gravity vector), and, conversely, that sample could spill or fall out of an open container not facing away from gravity.

3.6.5.3 Lighting Conditions

The sampling system will be capable of performing sampling operations for a sample cycle with or without natural lighting on the workspace. When lighting is available, documentation imaging will be performed at various steps in the sampling process. When adequate natural light is not available, these steps will be skipped to maintain a higher level of productivity over the short surface mission duration.

If lighting is required by instruments to observe or analyze delivered samples, the lighting must be provided by the instrument. Payloads must be capable of performing their operations during the Europan night.

Shortly after landing, a set of stereo images of the sampling workspace will be collected for building a DEM. This DEM will allow the ground operators and/or the onboard flight software to evaluate the terrain for sampling hazards, choose sampling sites and check robotic arm trajectories for safety considerations. During the Europan daylight period, a DEM may be created with new images to capture the newly excavated and processed terrain. Note that the azimuth of the Lander at landing is not targeted, and any orientation may result, e.g., the Workspace may be on the pole-ward side of the Lander and therefore be subject to some self-shadowing by the lander body and High Gain Antenna.

3.6.6 Sampling System to Payload Interfaces

The sampling system will be capable of either transferring sample into an instrument for further manipulation or presenting sample to an instrument for observation at a distance. Any further processing or preparation of the sample for analysis is the responsibility of the instrument.

The physical interface between each sampling instrument and the sampling system will be one 2 cm diameter cylindrical port in the vault wall per instrument. Proposers of instruments that will analyze surface samples must indicate if they require sample delivery or sample presentation (i.e., sample stays outside the vault and instrument interrogates the sample through a small window) to enable their investigation. Any specific requirements for geometry, materials, or sealing by the project-provided container should be described by proposers. If sample presentation is required, the distance from which observations must be made and any requirements on window materials should be described by proposers. The details of the interfaces between the sampling system and each payload will be further negotiated after instrument selection. See Table 3-6 for a summary of the interface options.

Table 3-6. Summary of options for the physical interface between sampling system and payloads.

Interface Type	Description	Details
Sample Delivery of Containerized Sample	Sample delivered within a container that is inserted into the instrument through 2 cm diameter port.	Container materials and end caps have options to be customized for instrument. Details to be negotiated after selection.
Presentation of Sample for Observation at a Distance	Sample brought to fixed distance from 2 cm diameter port for observation at a distance by instrument.	Distance between payload and sample can be customized for instrument. Fused silica window available as container end cap but window material can be negotiated after selection.

3.6.6.1 Payload Covers

The flight system will provide payload covers for all instruments observing and analyzing surface samples to protect against debris generated at landing and during sampling. The covers are mounted to the outside of the vault to guard against inadvertent hardware contact and reduce thermal losses. The cover mass and power required to heat and actuate the covers are not part of the instrument allocations. Covers will be actuated open and closed by the sampling system software as part of the sample presentation or delivery process. The covers will be able to open fully and move out of the way of the sample handling mechanism responsible for presenting or delivering the sample. The instrument will be exposed to the environment through the open cover for a period of time before sample delivery or presentation. The timing, duration, and software interface of when covers are opened and closed relative to scientific observation or sample handoff will be determined during phase B.

3.6.6.2 Sample Processing

As noted previously, no sample processing is provided by the sampling system (e.g., melting, filtering, desiccating, etc.). Samples are collected and delivered as-is and will contain a range of particle densities and particle sizes up to the maximum shown in Table 3-5. If sample processing is required by the proposed instrument (e.g., melting, filtering, desiccation, concentration, etc.), a description of the sample processing design and associated resources (mass, power, volume, time, etc.) should be included in the instrument proposal.

After payload selection, it may be determined during instrument accommodation that there would be a net benefit to combining the sample processing functions of multiple payloads into a common sample processing system. This trade study will be initiated after payload selection and negotiated with the instrument providers as part of the payload accommodation process.

3.6.6.3 End-to-end Sample Chain Testing

Testing of the end-to-end sampling chain, including both the sampling system and payload elements, will be critical for verifying the integrity of the hardware designs and interfaces. Selected payloads will be required to provide “front end” prototypes (referred to as Sampling Interface Testbed Hardware in Section 9) to enable early testing of the sampling to payload interfaces, in addition to Engineering Models (EMs) of instruments delivered at a later point. These "front end" prototypes must include any electromechanical components required for receiving, processing or handling sample. The fidelity of such units will be discussed in more detail as part of the payload accommodation process (i.e., after instrument selection).

3.7 Lander Attitude and Pointing

All instruments and other items mounted in or on the lander shall be designed to operate while tilted with respect to the local gravity vector by up to 30 degrees (a combination of local terrain slope and Lander tilt with respect to the terrain) for the duration of surface operations. Additionally, the azimuthal orientation will not be controlled during landing, and therefore the lander could be in any azimuth.

The pointing accuracy of the externally mounted camera gimbal is expected to be within approximately 1.35 degrees.

3.8 Power

The power system shown in Figure 3-8 is an unregulated, direct-energy transfer, balanced power bus operating at a nominal 28 V with a single-fault tolerant design.

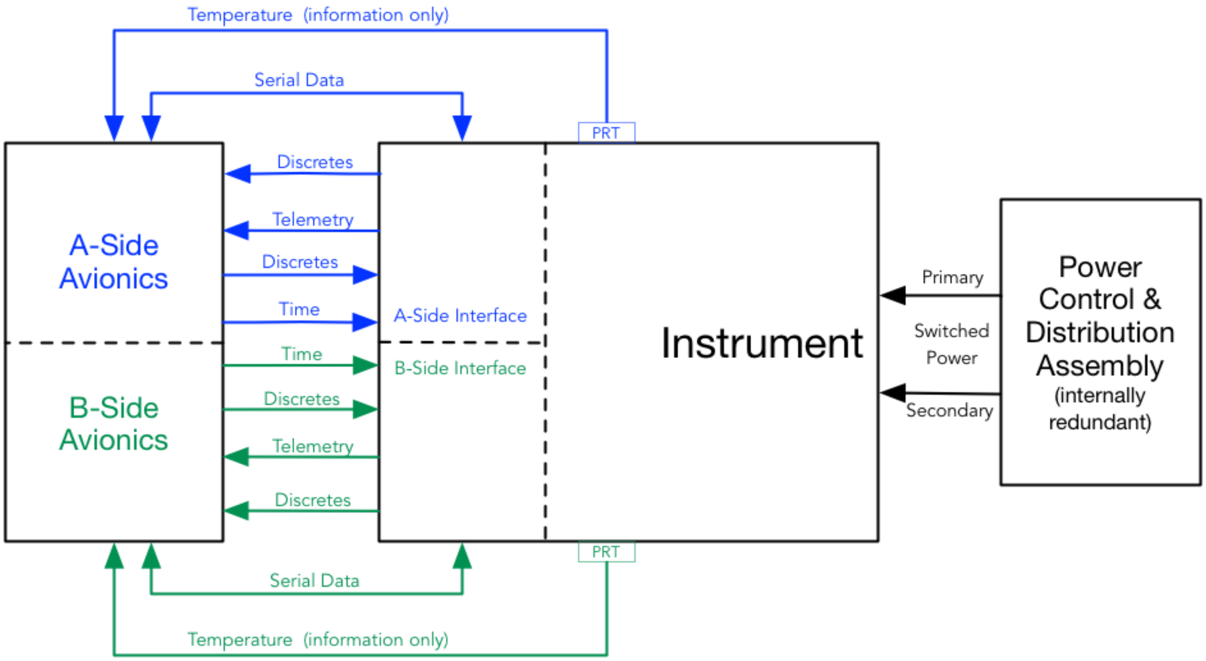

Figure 3-8. Power System Block Diagram

3.8.1 Payload Power Accommodation

Power availability is based on the total energy contained within the primary batteries. Battery capacity will be one of the determining factors relative to the total operational lifetime on the surface of Europa.

No energy sub-allocations are given to individual types of instruments; rather, there is an overall estimate of power and energy for the payload suite as a whole (see Table 3-2). Monitoring instruments may continue to operate beyond a sample cycle; however, it is important to keep each instrument's power level low with a special emphasis on minimizing the total required energy. Allocations for total energy consumption and operational time for instruments are discussed in Section 5.6.6. Proposals shall specify all operational modes and provide nominal and worst-case timelines of energy use during sampling and monitoring.

3.8.2 Payload Power Interfaces

Instruments should operate within specification using a direct-energy transfer, 28 V balanced power bus with a nominal range from 24 to 36 V. The voltage will vary with time, determined by the battery temperature, state of charge, and discharge current. All instruments should be tolerant of steady-state DC voltages between 0 and 40 V. The power interface of the instrument should protect against failure propagation. The instrument should survive an instantaneous intentional or unintentional switch-off on the external power line at any time in any configuration without degradation of nominal performance. The instrument should turn on in a way that limits inrush current and a current draw profile should be provided, including the maximum current draw transient expected (per Section 10). Additional information on power transient requirements can be found in the Environmental Requirements Document (ERD) (JPL D-97633), including inrush current limits (ERD Section 4.5.3.1.1)

The flight system will provide switched power to the payload at the bus voltage. All load channels will include resettable circuit breakers and provide current telemetry to the lander flight system. A single channel will be provided for each instrument. Proposers should specify whether a 2A or 5A load limit is requested. In addition, the CRSI will each be provided two 2A heater channels. The proposer should provide details on instrument fault containment and isolation regions.

Instruments should be compatible with a single-point ground (SPG) approach, whereby spacecraft primary power is kept isolated (typically > 1 MΩ, for both the active and return), and the instrument power conversion unit (PCU) provides the SPG for an instrument ground tree by referencing the secondary power return directly to the chassis. Instruments should provide all secondary voltage conversions required for their hardware. Grounding, bonding, and isolation requirements can be found Section 4.5.5 of the ERD.

3.8.2.1 Actuators and Covers

The lander spacecraft will provide the initiation command for release of deployable covers or mechanisms. Strong consideration for non-explosive actuators (NEA) is preferred. The flight system should be the initiator of actuations, releases, and deployments so that any safety or arm/enable functions are the responsibility of the flight system. Any circuit requiring a safety or arm/enable function should be explicitly identified along with a definition of the initiator load (including current profile over time). Safety inhibits, if any, should be independent, verifiable, and stable, and should stay in a safe position even in case of energy failure. Any irreversible event (e.g., one-time release) shall require 2 independent actions by the flight system (e.g., separate ARM and FIRE commands)

3.9 Instrument and Sample Thermal Control and Thermal Interfaces

Europa presents a challenging thermal environment, and the instruments are subjected to the same thermal design challenges as other elements of the lander. Europa is very cold with the temperature of the surface being between 70 and 130 K, depending on the location. The atmosphere is extremely thin, essentially a hard vacuum (10^{-12} bar).

The instruments will be mounted and coupled (mechanically and thermally) directly on the lander vault walls or be isolated (mechanically and thermally) from them via structural supports that have appropriate levels of thermal isolation.

The lander vault walls will be thermally controlled by the flight system to be within the following temperature range at the vault interior wall interfaces: –40 to +50ºC, and the vault walls serve as the thermal sink (if thermally coupled) and interface for the instruments mounted on them. Thermal control of the vault is achieved by passive thermal means like multi-layer insulation (MLI) blankets, electrical heaters, thermostats, heat spreaders, and thermo-optical coatings. Instruments shall be able to achieve full performance operation anywhere within the above range of interface temperatures. Analytical instruments receiving samples are likely to have a particularly challenging thermal design, given the likely desire to thermally control the cryogenic sample received by one part of the instrument, yet take advantage of the thermal and radiation shielded environment of the vault for electronics and other sensitive components. Proposals should be specific with respect to thermal requirements, design approach, and accommodation features regarding thermal design at the instrument–sampling system interface in order to facilitate accommodation assessment. If there are any specific cooling requirements, the instrument needs to provide the radiative space required or other methodology. If radiators are needed, the instruments need to account for the associated mass and energy, and the proposal should specify the volume and FOV requested. Constraints on the accommodations of radiators in the lander, e.g., area, location, field of view, thermal isolation, etc. will be addressed after selection. Any thermal isolation required by the payload shall be part of the payload design and specified in the proposal.

Thermal control of hardware mounted outside of the lander vault is done with a combination of survival heating (electrical), thermal isolation, and heat-to-use.

The sample temperature will be maintained at a value specified in Table 3-5 prior to transfer or presentation to minimize sample loss by sublimation. Once the sample is delivered into the instrument, the thermal management of the sample is the responsibility of the instrument. The effects of the vault interface temperature range of –40 to +50ºC on sample handling and composition within the instrument should be considered.

All proposals must describe the thermal control design for the proposed instrument. The Instruments proposing to locate hardware in locations other than those discussed above will be responsible for their own thermal management and must allocate power resources accordingly, within the overall payload power allocation. Specific mechanical configuration of any thermal interface will be developed after instrument payload selection.

Redundant temperature sensors with an interface direct to the Flight System avionics will be incorporated into each instrument for the purposes of thermal monitoring while the instrument is powered off.

3.9.1 Instrument Thermal Design Requirements

The expected thermal interface temperatures for lander vault walls are in the range of –40 to +50ºC, so these will be employed as the allowable flight temperature (AFT) limits at the interface of the vault-mounted hardware. However, the vault wall-mounted hardware will need to be qualified to operate over a wider temperature range of –55°C to +70°C at the interface. Maximum local heat fluxes (W/m^2) dissipated on the vault walls by the instruments will be provided to the flight system thermal engineer to ensure that local interface temperatures can be maintained within the above range. Inside the vault enclosure, the instruments and samples will be subjected to infrared (IR) radiation from vault and component walls (–40 to +50ºC).

Hardware mounted on the outside of the vault enclosure must be designed and tested to survive the following thermal environments. Depending on the location of the hardware (or sample) and its orientation, they will experience three kinds of thermal environments:

1. IR Radiation:
   - Sky, Europa ground (values provided in ERD JPL D-97633)
   - Exterior surfaces of lander
     - Covered with MLI blankets (<250 K)
     - Not covered with MLI blankets (50 to 323 K)
2. Solar radiation (values provided in ERD JPL D-97633)

Hardware mounted outside the vault will be thermally isolated from the warm lander to minimize parasitic heat input or loss.

During the cruise phase, the spacecraft will provide a thermal environment to instrument located within the vault consistent with the surface phase environment. All hardware that is either external to the vault or includes a penetration thru the vault wall (e.g., sample transfer port) is subject to direct solar illumination during early cruise at a sun distance of as little as [0.89] AU, including

1. CRSI cameras mounted on HGA and associated cabling
2. Sample Transfer Port Covers
3. Any other possible vault penetrations requested by instrument proposers (e.g., atmospheric sample port; sample sublimation gas-phase exhaust port, etc)
4. Any other possible hardware external to the vault requested by the instrument proposers (e.g., radiators)

3.9.2 Instrument Thermal Design Considerations

Thermal control complexity and optimization is a system-wide issue. In general, greater optimization and overall efficiency is best achieved by an integrated thermal design. With this in mind, instrument designs should minimize the use of integral (i.e., internal) survival heaters in favor of either not requiring survival heating or requesting flight system support for survival heating. Only electrical heating is permissible for this function (no nuclear sources will be allowed). The power necessary to provide bulk thermal accommodation (within the vault) will be book-kept by the flight system. Any survival or functional power needed for instruments mounted externally to the vault will be the instruments' responsibility (from within their own power allocation). It is the responsibility of the instrument to size, design, procure, and implement the heaters in their instrument. Instrument proposals must include an estimate of these loads in their thermal design description including the energy required for survival energy of their instrument outside the vault.

Any requirement for thermal control, heating, and/or cooling internal to the instrument will be the responsibility of the instrument, and required power must be accounted for in the instrument operational power timeline.

3.10 Electrical,Cabling, and Grounding

The cabling on the lander takes cues from the Mars Science Laboratory (MSL) rover as well as Europa Clipper wherein electronics boxes are fastened to a common mounting panel with connectors located on their opposite face. The harness is then guided to the side of the electronics box, bundled, and routed between the electronics boxes. This method of packaging allows electronics boxes to be located close to each other while allowing for clearance for harness backshells and bend radii above the electronics boxes. In addition, this allows for mate/de-mate operations to be performed fully in view and minimizes the possibility for blind mates. Proposals should indicate in configuration diagrams the location of external connectors (both Flight and Direct Access or Ground Support Equipment).

The harness within the vault will be twisted pairs or twisted shielded pairs depending on the function. Overwrap for the general harness is currently not present within the vault. External to the vault, the harness will have overwrap which terminates at the vault wall wherever the harness penetrates the wall. The harness components shall be approved by the materials and processes engineer as well as the flight system harness engineer unless they are selected from the Preferred Parts and Materials List. It should be noted in instrument proposals where any special requirements are necessary, such as direct access connections or harness or connections requiring large bend radii, such as large bundles or fiberoptic lines. Connector interface locations on the proposed instruments should be placed in locations where they have easy access to the cabling troughs as well as allowing for clear visible access during assembly.

3.11 Spacecraft Avionics

The lander avionics consists of the command and data handling (C&DH) hardware integrated with the flight software (FSW). During the surface mission, the data generated by the instruments and engineering subsystems will be stored in non-volatile memory that is part of the avionics subsystem, and deleted if necessary only after confirmation of receipt on the ground. To conserve energy and to manage thermal dissipation within the vault during the surface mission, the avionics subsystem will periodically sleep (see Section 3.11.1.4.)

The avionics subsystem communicates with each of the instruments via a full duplex SpaceWire or via a full duplex universal asynchronous receiver/transmitter (UART). The instruments should receive all commands via this serial interface, and transmission of all data generated by the instrument should also use this serial interface.

3.11.1 Spacecraft Flight Software

The behavior of the flight system is orchestrated by on-board software within the spacecraft computing system. The spacecraft FSW will be modular, written in a high level, compiled language, and will operate in a real-time, multitasking environment with layered designs and protocols.

Key tasks of the spacecraft FSW include:

- Management of time, power, temperature, switches, relays, deployment mechanisms, sample acquisition and transport systems, and the intercommunications system.
- Cognizance and control of spacecraft subsystem hardware (including instruments) and associated functions.
- Coordination of sampling among the sampling systems, imaging, and instruments.
- Uplink and command handling.
- Storage and execution of planned activities.

- Collection, handling, management, compression (if needed), and transport of data (including science and calibration) to the ground for both science and engineering ground operations.
- Command and data handling to and from instruments.
- Management and coordination of system resources.
- Avoidance of conflicts and constraint violations.
- Detection of and response to system faults or unexpected events
- Support for software maintenance functions such as code and parameter updates

3.11.1.1 Spacecraft FSW Instrument Management

Control and management of each instrument will be implemented in a unique software component for each instrument (a.k.a. an “instrument manager”). The specific details of this management and control will be negotiated after selection.

The instrument manager component within the spacecraft FSW issues “instrument commands” to the instrument. Instrument commands are forwarded by the FSW in response to ground commanding (i.e., spacecraft commands) or constructed autonomously to support interaction and management of the instrument. The Ground Operations team including members of the instrument team define and construct spacecraft commands, command sequences, or desired state over specified time periods that are sent to the vehicle. The instrument manager coordinates the sending of instrument commands to the instrument via the serial interface at the appropriate time or event-coordinated condition.

The instrument team will provide a command dictionary to the project (see Table 9-2) complete with a specification of every instrument command and parameter that can be commanded and operated on by the instrument including resulting resource usage (power, thermal, etc.) and engineering and science telemetry generation. If stored data tables and/or parameters are used for instrument control, the commands or directives used to update these tables need to provide the same visibility. The flight software implementation of any basic instrument manager functionality will be performed by the Project.

Instrument engineering/housekeeping data will be examined by the instrument manager component, which extracts the portion of the instrument state and status that is needed for on-board evaluation and coordination. This includes identifying and reacting to faults or errors when the avionics is awake. Instrument designs in which faults are detected and responded to within instrument software are encouraged. Proposers should specify any specific fault conditions for which spacecraft FSW is requested to react as necessary including possibly powering off an instrument.

3.11.1.2 Spacecraft Data Processing

Instruments are expected to provide computational capabilities and sufficient buffering so that they do not require servicing by the FSW for their nominal science collection functions. This means that the instrument should internally perform any instrument-specific, algorithmically complex, low-latency, closed-loop, or data analysis functions. Similarly, the instrument primitive actions necessary to manage the science and engineering data collection should be incorporated within the instrument logic itself. Instruments that desire to be operational while the lander is asleep (e.g., the Geophysical Sounding System) must be able to provide computational capabilities and sufficient buffering so that they do not require servicing by the FSW for up to 24 hours. As shown in the surface scenarios in Section 5, sample analysis by instruments will predominately be during periods with the Lander asleep to better conserve energy. Instruments which do not intend to operate when the lander is asleep must be able to provide computational capabilities and sufficient buffering so that they do not require servicing by the FSW for up to 5 minutes. Instruments which intend to operate for more than 1 hour must be able, after completion of an observation, to enter a low-power mode wherein they are able to retain their data. Data collection by Lander avionics from the instrument may be as much as 24 hours later.

The science data collected by the instrument will flow through the FSW and be stored on a bulk data storage unit with the avionics. The FSW will offer an opportunity to compress the data prior to packetization and downlink. The instrument should identify data compression opportunities and whether this compression would be better implemented in the instrument, in the Lander electronics or software, or shared.

3.11.1.3 Special Processing Needs

Instrument teams should identify any additional instrument- or investigation-unique functionality that could be hosted in the FSW that results in an overall power, mass, and/or cost savings. Post-selection definition of such functionality will involve design analysis, interface definition, algorithm definition and/or inheritance, and implementation within the constraints of the FSW architecture. Implementation of any instrument-unique post-processing in the FSW will need to be negotiated along with the algorithm delivery schedule.

3.11.1.4 Sleep Mode

The available energy in the lander design is dependent on the capability of single use primary batteries. To conserve energy, and thus mission life, the lander avionics can “sleep,” which eliminates the power needed to run the lander avionics themselves. The cadence of “lander awake” and “lander asleep” is the nominal operational model.

With the possible exception of the CRSI, the necessary operation duration to support science investigations will likely result in the requirement for instruments to operate when the lander is “asleep” (see Section 3.11.1.4.1). Instrument proposals should describe in detail the operational model both while the lander is awake and while the lander is asleep. While the lander avionics are asleep, hardware monitoring and control of certain spacecraft functions continue to be maintained by the lander. The lander will be able to continue to operate coarse thermal control to maintain control of surface temperatures.

3.11.1.4.1 Operation While Lander Is Asleep

If an instrument will require a specific lander wake/sleep operational cadence, then this must be identified in the proposal and will be subject to negotiation.

Instruments that propose to operate autonomously while the lander is asleep will be required to:

- Be self-reliant from a health and safety perspective.
- Collect and store/save science data for future retrieval by the spacecraft
- Recover in known state needing </= 1 command cycle to restart activity.

3.12 Data Interfaces and Data Storage

Instruments should communicate with the spacecraft computing system via serial interface. Each instrument must include two independent serial-interface communication interface channels in order to cross-strap with redundant spacecraft computing system elements. Except for monitoring points that are required when an instrument is unpowered (such as for temperature), the serial communications interface will support all command and telemetry needs, as well as time distribution, fault management, software maintenance, and other items.

Instruments shall have internal data buffers. The sizes of the data buffers are a function of the data rate of the instrument's serial communications interface and the instrument rate of data production.

Any interfaces, in addition to the serial communication interface, should be specified. Discrete interfaces should be DC or galvanically isolated and will be evaluated for compatibly with spacecraft capabilities.

3.12.1 Instrument Interface Definition

In order to support development of the instrument-to-flight-system interfaces and the baseline FSW capabilities, each instrument team will be required during the development phase to provide the following system engineering support:

- Full definition of the instrument interfaces including data buffering, protocols, and transactions (input and output) on the instrument side of the interface.
- Full definition of instrument data structures that cross the instrument/avionics interface for the purpose of FSW and ground derivation of instrument status, health, errors, and anomalies.
- Definition of the baseline capabilities implemented in the spacecraft FSW. This includes: instrument hardware interface, instrument state determination (including instrument health monitoring), instrument control (including both commands sent to the spacecraft and commands sent from the FSW to the instrument), instrument data product generation (including ancillary data), expansion of instrument activities, instrument operational constraints and interactions with other spacecraft activities, etc. The instrument team should identify this support in the system engineering role statements.
- Definition of and verification of Project-developed software simulations of the instrument. Nominally, these simulations are limited to providing realistic fidelity of the communication and data volume, particularly command / response with delays representing command execution, and do not typically require simulation of the science-sensing functionality.

3.12.2 Instrument Data Interface

The lander can provide either a high-speed (~200 Mbps theoretical) or low-speed (~100 kbps theoretical) serial interface. The high-speed interface is a SpaceWire interface based on standard ECSS-E-ST-50-12C. The low-speed interface is a universal asynchronous receiver transmitter (UART) interface implemented as low voltage differential signaling (LVDS). The command and telemetry protocols of all serial interfaces shall make use of the Packet Utilization Standard ECSS-E-70-41A on top of CCSDS Space Packet Protocol 133.0-B-1.

In order to protect the avionics from instrument faults or failures that might otherwise damage the electrical interface, instruments are required to use specific end-circuit designs that comply with fault containment and grounding principles. To reduce interface analysis and ensure compatibility with the Europa radiation environment physical layer parts must be selected from the Preferred Materials and Processes Selection List (PMPSL), JPL D-92600.

3.12.3 Compression Services

The avionics FSW can provide data compression (with algorithm tailored for data type) for instrument data prior to downlinking; this does not preclude any instrument-based solution for compression. If compression is desired, the instrument should identify constraints on compression and whether raw data is needed for calibration.

3.12.4 Timing Services

Instruments should time-tag science/reconnaissance, instrument engineering, and instrument housekeeping data. The lander design provides timing updates from the spacecraft avionics once per second with an accuracy of at least ±1 ms while the lander is awake. When the lander is asleep, no timing updates will be provided. Between timing updates, instruments that are on should maintain time internally to a resolution of ±1 ms. The instrument should time-tag collected data with the instrument-maintained time which can be correlated with spacecraft time after the Lander wakes up. If better timing is required, the instrument proposal should identify timing needs.

3.12.5 Spacecraft Telemetry

The spacecraft avionics can provide spacecraft telemetry if required. The instrument proposal should specify any spacecraft data requests and associated rationale.

3.12.6 Instrument-PRT Interface

Temperature monitoring of the instruments by the flight system is required both when the instrument is operational and when the instrument is powered off for health and safety purposes. Instruments shall provide access to two thermal zones each of which has two (redundant) platinum resistance thermometer (PRT) measurements for flight system evaluation. These PRTs should be directly pinned out to instrument connectors to be interfaced directly with Flight System Avionics. If an instrument requests additional PRTs to be read directly by the flight system while the instrument is powered off, instrument proposers must document the number and purpose of each. Priority will be given for those measurements critical to instrument health and safety.

For PRTs that are measured by the lander flight system, the project will provide a reasonable number of qualified PRT parts to instrument teams for use in flight units. For EM, prototype, and ground test units, the Project will provide part numbers for instruments to acquire PRTs.

3.13 Fault Management

The fault management challenge for the surface mission is containment of both transient and permanent errors while maximizing science return for the limited mission duration. The continual pursuit of mission objectives is paramount since the surface mission is exceptionally challenged in regard to the useful lifetime of the vehicle on the surface. The overall fault management philosophy is, therefore, biased toward continuing operations in the presence of faults. This means that both the spacecraft and instruments will be designed to detect, identify, and recover from anomalies autonomously and independently as the first tenet of that philosophy. Complementary to that tenet is the presumption that mission lifetime is constrained primarily by energy available. Both the instrument and spacecraft fault management are optimized to maximize the useful surface vehicle lifetime.

The following sections address design and implementation expectations for the instruments. Proposers are expected to be responsive in their proposal to concerns and topics identified in the following sections.

3.13.1 Spacecraft Fault Tolerance

Both instruments and the spacecraft system are susceptible to faults, errors, and interruptions. The spacecraft will similarly be designed to recover and continue its activities without interrupting instrument activities, if possible. Instruments are expected to recover and continue as autonomously and independently as possible for self-detected faults. The shared goal is the continuation of science activities in the presence of any faults and must be a cooperative effort between the spacecraft and the instruments.

To establish this coordination, the information exchange from instrument to spacecraft will need to convey the internal instrument state and configuration details if the spacecraft is responsible for reconfiguration and restart of the instrument.

Instrument designs and implementation must also be resilient to spacecraft-initiated responses to spacecraft faults (likely unrelated to the instruments). This includes computational interruptions, internal communication interruptions, and energy, thermal, and power consumption excursions or limit violations. In these scenarios, the spacecraft may be required to take unannounced actions that affect instrument operations, for example powering off an instrument without preamble or announcement. Instruments need to be tolerant to this scenario and should include design and implementation strategies to ensure no health, safety, consumables, or lifetime is affected.

3.13.2 Instrument Fault Tolerance

Instrument proposals are expected to describe how instrument anomalies and faults will be tolerated, detected, identified, recovered from, and in some cases masked. Proposals shall discuss how instrument mission-ending single-failure considerations are addressed in design and/or should identify technical rationale and mitigations that ensure high reliability for the entire mission lifetime. Instruments must assume that their experiment may, in actual operations, be scheduled anytime during the mission, and therefore be designed to survive the environment through the full mission duration. Proposals shall describe the expected operational characteristics in the presence of faults and anomalies.

3.13.2.1 Instrument Implementation Considerations

Proposals shall specifically address the scenario where an instrument fault occurs while the spacecraft avionics are powered off and how the instrument ensures its own health and safety. If an instrument will require a specific operational cadence or interaction with the spacecraft avionics, then this must be identified in the proposal and will be subject to negotiation.

The preservation of collected science data is a priority and the instrument and flight system design must ensure neither degradation nor loss of data in the presence of faults or environmental effects. Instruments should consider storing data in non-volatile memory with error correction functionality (or data replication) as an intrinsic capability. Strategies of this type provide robustness against science data loss for several fault and power loss scenarios. In addition, the retention of data in non-volatile memory enables flexibility and energy conservation strategies such as selectively powering on/off instruments to transfer data at a later time. Proposal responses shall describe how science data is protected from loss in the presence of faults, errors, or spacecraft-induced power-off conditions.

The instrument design and implementation is expected to preserve the independence or “fault containment” boundaries between the spacecraft and the instrument[1]. In theoretical terms, this means ensuring that thermal, mechanical, electrical, and informational interfaces do not permit a fault or error in the instrument from propagating to either the spacecraft or other instrument(s).

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[1] Instruments must do no harm to the spacecraft at any time including test, cruise, DDL, and surface operations.

This includes interferences (mechanical, electrical) and disruptive or destructive influences (shorts, repetitive interrupting, etc.). For example, in order to protect the spacecraft avionics from instrument faults or failures that might otherwise damage the electrical interface, instruments are required to use specific end-circuit designs and follow JPL power bus and grounding requirements. Proposal responses shall describe how instruments prevent instrument faults from affecting the spacecraft or other instruments.

Instruments that have irreversible internal actions (e.g., releases) must disclose the success or failure of those actions, so coordinating logic in the onboard plan can choose alternative subsequent actions. First actions after landing will be automatically executed, and instruments must be designed to perform these without requiring a ground-in-the-loop (GITL) cycle, e.g., internal releases, self-tests, calibrations, etc. For instruments that ingest or otherwise process samples, the instrument should be designed so that it is ready for a second or subsequent sample (if no explicit fault occurs) without any need for a time-consuming GITL cycle. Proposal responses shall describe the concept of operations for the instrument including the expected coordination with the spacecraft. Specifically, the proposal shall describe how the instrument design will support automatic/autonomous activities and shall specifically describe what state, results, or status information will be observable and available for use within the spacecraft plan logic.

Lastly, instruments with computation and software should be designed so that update of the software is possible in flight. The flexibility to change software may be necessary during the cruise and pre-landing mission phases even if a post-landing instrument software update is unlikely because of the limited surface mission duration.

3.13.2.2 Instrument Fault Testing

Fault mitigation verification often requires extraordinary measures to enable adequate test coverage. The instrument design and test environment should support the injection of error conditions and faults via either the spacecraft interfaces or test-only interfaces in order to verify the appropriate identification and reactionary behaviors of the instrument (e.g., instrument internal fault protection). Instrument teams should identify fault cases and scenarios that cannot be stimulated/injected, or are prohibitively difficult to inject. The instrument and spacecraft may conduct integrated verification to ensure correct overall system behaviors. Proposals shall describe how instrument fault protection and fault tolerance attributes are verified and validated.

3.14 Telecommunications

To avoid confusion about uplink and downlink, we traditionally use the terms Forward Link and Return Link when discussing Earth-to-lander and lander-to-Earth transmissions, respectively.

The lander telecommunications subsystem will be used for ground operations to send commands to the lander and return engineering telemetry and science data to Earth using direct to Earth (DTE) and direct from Earth (DFE) communications with the DSN. The Lander includes both a Low-Gain Antenna (LGA) and High-Gain Antenna (HGA) to enable data return to Earth.

3.14.1 Instrument – Telecom Constraints

The telecom operations will be transparent to the instrument teams. The primary telecom concern for instrument functionality is to avoid EMI/EMC issues and the shared pointing of the HGA and Cameras. In particular, the instruments cannot produce signals (noise) in the X-Band receive bandwidth at a level sufficient to interfere with forward link (to the lander) reception. The details of the EMI/EMC exclusion bands are found in the Project ERD; non-compliances should be identified and justified in the proposal, and may result in the instrument not being able to operate during telecom relay sessions.

3.15 Planetary Protection

Payloads proposed for Europa Lander must focus on requirements for bioburden reduction and verification. These Europa Lander payload requirements flow down from overall mission requirements to limit the probability of contamination to less than 10^{-4}. The formal statement of the Europa lander mission PP requirement is derived from NPR 8020.12D:

> "The mission design of Europa lander, as a spacecraft that will land [and potentially inadvertently impact the Europan surface prior to landing] shall be compliant with the requirements of PP mission classification Category IV under current COSPAR and NASA PP policy: i.e. *less than* 1×10^{-4} *probability of contaminating the Europan ocean by a viable Earth microorganism*."

Payload requirements related to Planetary Protection can be found below.

The following documents, or the latest approved versions, are applicable:

- NPD 8020.7G Biological Contamination Control for Outbound and Inbound Planetary Spacecraft (Revalidated 11/25/08).
- NPR 8020.12D, Planetary Protection Provisions for Robotic Extraterrestrial Mission, Rev. D, April 20, 2011 (Requirements, including guideline on planetary protection categorizations).
- Committee on Space Research (COSPAR) Planetary Protection Policy, 20 October 2002 (as amended December 2017).
- ECSS-Q-ST-70-57C (first issue, 30 August 2013), Dry heat bioburden reduction for
- Flight hardware.
- ECSS-Q-ST-70-56C (first issue, 30 August 2013), Vapor phase bioburden reduction for flight hardware.
- NASA-HDBK-6022 (17 August 2010), Handbook for the Microbial Examination of Space Hardware

3.15.1 Bioburden Reduction Processing

The system-level PP requirement outlined above flows down to payload- and spacecraft-level PP requirements by assuming that all hardware will be processed using a bioburden reduction process prior to encounter with Europa.

Pre-launch, the principal techniques used for bioburden reduction prior to integration with the launch vehicle (L/V) are:

1. **Dry heat microbial reduction (DHMR) / heat microbial reduction (HMR).** DHMR is a bake-out process where the hardware is held at an elevated temperature (typically >125°C) for many hours with or without controlled humidity. At the microbial reduction levels required for Europa Lander (≥4-log reduction), the specification, as given in section 5.3.1.2 of ECSS-Q-ST-70-57C, does not require humidity control and is denoted here as Heat Microbial Reduction (HMR). Key time and temperature data for HMR is provided in Table 3-7.

   a. Proposers should note that payloads and payloads elements located outside the Lander vault will require 6-log reduction process which, for HMR, requires temperatures >125°C
   b. Time and temperature margins are generally added to ensure the HMR process meets requirements in the event of temperature variances. Values shown in Table 3-7 include a 25% margin on duration; temperature margins are typically 3°C. Alternate approaches are acceptable and shall be determined in conjunction with the project PPE.
   c. Any specific components that are not compatible should be identified, and for these components the maximum temperature at which HMR would be viable should be specified.
2. **Vapor Hydrogen Peroxide (VHP) processing.** VHP is a gas-phase microbial reduction process that can perform up to 6-order bioburden reduction or full sterilization, depending on application parameters (see section 5.3.1, ECSS-Q-ST-70-56C, 30 August 2013). As a gas-phase chemical method, VHP is limited to *surface* sterilization.

At the payload level, the Project assumes that instruments shall be delivered at cleanliness levels compatible with achieving the microbial cleanliness requirements of the system-level bioburden allocations. To this end, it is anticipated that prior to delivery for system integration, the following shall be required (see Table 3-7 for temperatures and durations):

- Payload elements inside the lander vault shall be required to perform a surface **4-log (4 orders of magnitude) HMR bioburden reduction prior to delivery and be compatible with additional 4-log reduction upon re-work**
- Payload elements outside the lander vault shall be required to perform an encapsulated **6-log (6 orders of magnitude) HMR bioburden reduction and shall be compatible with VHP treatment behind the biobarrier after integration**.
- To maintain cleanliness levels during shipment and prior to integration, **payloads shall be delivered to ATLO in a biobarrier or similar sealed enclosure**. Such a delivery enclosure and associated handling constraints should be described in the proposal and will be provided by the payload provider.

Payload providers shall confirm that their instrument will function within specification(s) following bioburden-reduction processing. Providers should consider whether calibration is needed after bioburden-reduction processing and how it may be accomplished without compromising the microbial cleanliness of the spacecraft. Providers shall plan to accommodate multiple exposures to bioburden reduction processing, in the event spacecraft rework is necessary.

At the spacecraft level, the lander currently assumes that the major spacecraft systems; i.e. the Cruise Stage (CS), Bio-Barrier, Deorbit Stage (DOS), Descent Stage (DS), and lander will be delivered to Kennedy Space Center (KSC) for final system integration and test only after bioburden reduction methods have met each system’s overall bioburden allocation. Prior to and after assembly, VHP treatment may be used to treat external surfaces of systems on the DOS-DS interface and the final, integrated “launch stack” within the Bio-Barrier prior to integration into the launch vehicle. This approach is in contrast to system-level D/HMR bioburden reduction processing for the entire launch stack, which is *not* assumed.

Table 3-8 summarizes anticipated requirements that the NASA PP policy will impose upon Europa lander (blue column), along with corresponding impacts to instruments (orange boxes in blue column), Table 3-8 provides an example of payload provider data requirements; Planetary Protection documentation requirements are specified in NPR 8020.12D.

Table 3-7. HMR Specification. Duration (hours) to achieve 4- or 6-order reduction in bioburden. The required minimum temperature (>125ºC) for 6-order reduction is highlighted in yellow. Note that higher temperatures greatly reduce treatment time and that temperatures up to 3ºC higher than target may be applied to ensure calibration and drift errors do not compromise compliance

Temp (°C)	Payloads Inside Lander Vault Treatment Duration (hours) for 4-log Reduction			Payloads Outside Lander Vault Treatment Duration (hours) for 6-log Reduction		
	Surface	Mated	Encap-sulated	Surface	Mated	Encap-sulated
110	70.5	140.9	704.6	n/a	n/a	n/a
115	60.1	120.2	601.1	n/a	n/a	n/a
125	44.3	88.6	442.9	n/a	n/a	n/a
126	43.0	86.0	429.9	129.0	257.9	1289.7
130	38.2	76.5	382.3	114.7	229.4	1146.9
135	21.4	42.7	213.7	64.1	128.2	641.0
140	12.1	24.2	121.0	36.3	72.6	363.1
145	6.9	13.9	69.5	20.8	41.7	208.5
150	4.0	8.1	40.4	12.1	24.3	121.3
155	2.4	4.8	23.8	7.1	14.3	71.4
160	1.4	2.8	14.2	4.3	8.5	42.6
165	0.9	1.7	8.6	2.6	5.1	25.7
170	0.5	1.0	5.2	1.6	3.1	15.7
175	0.3	0.6	3.2	1.0	1.9	9.7
180	0.2	0.4	2.0	0.6	1.2	6.0
185	0.1	0.3	1.3	0.4	0.8	3.8
190	0.1	0.2	0.8	0.2	0.5	2.4
195	0.1	0.1	0.5	0.2	0.3	1.6
200	0.0	0.1	0.3	0.1	0.2	1.0

Table 3-8. Europa Lander PP requirements. Instrument impacts are highlighted in orange.

Planetary Protection Requirement Short Description	Anticipated Europa Lander Requirement/Constraint	Additional Comments relevant to Instrument Proposers
PP mission-level	The Europa Lander mission shall be rated Category IV, per NASA Planetary Protection Document NPR 8020.12D, and meet the associated criteria of this rating.	At the spacecraft level, there is a series of requirements governing compliance with, e.g., impact avoidance with Europa and other bodies, which do not affect instrument requirements. These are not discussed in this document, but share the parent requirement.
Europa contamination probability	The Europa Lander Project shall ensure that the probability of contamination of a subsurface ocean at Europa by a viable Earth microorganism shall not exceed 1×10^{-4}.	This is the governing requirement for the cleanliness requirements that are imposed on the instrument hardware.
Ganymede contamination probability	The Europa Lander Project shall ensure that the probability of contamination of a subsurface ocean at Ganymede by a viable Earth microorganism shall not exceed 1×10^{-4}.	Compliance with NPR 8020.12D.
Callisto Contamination Probability	The Europa Lander Project shall ensure that the probability of contamination of a subsurface ocean at Callisto by a viable Earth microorganism shall not exceed 1×10^{-4}.	Compliance with NPR 8020.12D.
PP implementation management	The Europa Lander Project shall generate PP plans and reports, and hold PP compliance reviews according to NPR 8020.12D.	Instrument providers will need to generate and document approaches to planetary protection, which will require approval by the Europa lander Project. The instrument provider will need to submit PP authorization and summary form to the Project prior to the start of each PP procedure. A Project representative and/or a representative of the NASA HQ Planetary Protection Officer (PPO) may choose to witness and/or verify any required PP procedure. Procedure data must be recorded and submitted to the Project for review and closure.
PPO documentation access	The Europa Lander Project shall provide the PPO and/or designee access to technical and programmatic documentation related to the Project.	Compliance with NPR 8020.12D.
PPO bioassay access	The Europa Lander Project shall make appropriate arrangements to allow the PPO, and/or designees, once properly trained, to conduct bioassays on flight hardware and controlled environments, including launch site, during the course of the Project.	Compliance with NPR 8020.12D.
PPO access during hardware transport	The Europa Lander Project shall, at the request of the PPO, make appropriate arrangements to allow the PPO, or designee, to be present during the transport of the bioburden controlled flight hardware and during the launch operations.	Compliance with NPR 8020.12D.
HMR microbial reduction compatibility	For all Flight System components not compatible with heat microbial reduction (HMR), the payload provider shall coordinate with the Planetary Protection Engineer to identify and implement an alternative microbial reduction process for interior/mated surfaces and bulk materials.	Payloads inside the Lander vault shall be compatible with 4-log HMR processes; payloads or payload elements outside the Lander vault shall be compatible with 6-log HMR. Payloads shall be plan to accommodate additional HMR process applications to re-establish biological cleanliness after re-work.
VHP microbial reduction compatibility	For all exterior flight system components not compatible with vapor hydrogen peroxide (VHP), the payload provider shall coordinate with the PPE to identify and implement an alternative surface sterilization process.	Payloads and payload elements located outside the vault shall be compatible with 6-log reduction VHP processes. VHP is planned for use late in ATLO on the exterior surfaces of the DOS, DS and Lander (i.e. behind the biobarrier).

Planetary Protection Requirement Short Description	Anticipated Europa Lander Requirement/Constraint	Additional Comments relevant to Instrument Proposers
Exposure to damp swab/wipe sampling	For all flight system components not compatible with swab and wipe assay approaches, the payload provider shall coordinate with the PPE to identify and implement an alternative sampling process.	Water based sampling is a standard approach for surface bioassays. Payload providers should evaluate material compatibility with small amounts of water (≤1ml per 50 cm^2). Where incompatibilities exist, alternatives should proposed and will be evaluated by the project.
Alcohol-wipe cleaning	For all flight system components not compatible with occasional alcohol-wipe cleaning, the payload provider shall coordinate with the PPE to identify and implement an alternative surface cleaning process.	Alcohol-wipe cleaning is a standard approach for surfaces. Payload providers should evaluate material compatibility with alcohol-based solvents. Where incompatibilities exist, alternatives should proposed and will be evaluated by the project.
Cleanroom assembly	Spaceflight hardware shall assemble and maintain spacecraft and payloads in monitored and verified Class 10,000 (ISO 7), or better, cleanrooms in the operational mode.	Needed to maintain hardware cleanliness and keep bioburden low before microbial reduction process. More stringent cleanroom standards may be required for contamination control or instrument specifications.
Recontamination prevention during I&T	The Europa Lander Project shall use localized non-flight biobarriers/covers on hardware during integration activities, when hardware is not being worked on, and during test activities.	Needed to prevent recontamination during assembly and testing to maintain appropriate bioburden levels. Instrument providers will need to provide filters (e.g., HEPA filters) on enclosures.
Recontamination prevention following microbial reduction	Flight system components shall be protected from recontamination between any microbial reduction process(es) and prior to integration into the next level of assembly.	Needed to prevent recontamination after microbial reduction such that appropriate bioburden levels are maintained at delivery.
Launch vehicle recontamination prevention by blanketing	Flight system components not protected by HEPA filter(s) or completely unshielded from the Jovian radiation environment shall be protected from recontamination by use of blanketing or other protective cover, or with an alternative protection method acceptable to the Project PPE.	The Lander will be encapsulated in a Biobarrier (see Figure 3-3), and therefore this requirement does not apply directly to individual payloads
Access for bioassay sampling	Flight system component surfaces shall be made available for bioassay sampling immediately prior to last available access.	Bioassays are required for the bioburden estimate, in compliance with PP requirements. Assumptions regarding pre-delivery bioassays for instruments are 10-12 events over the course of the build (e.g. 1 per month). The bioassay schedule will be designed in coordination between JPL and the instrument provider and detailed in the project's Planetary Protection Plan and/or subsidary implementation documents.
PP required documentation information	All owners of flight system hardware shall provide hardware information to the PPE by the following project milestones: • Preliminary Design Review (PDR) • 6 months prior to Critical Design Review (CDR) • Hardware Requirements Certification Review (HRCR) The information required includes: free surface area, mated surface area, volumes of bulk materials, material content, any coatings, and plans and/or documentation of microbial reduction processes including any high-temperature processes during manufacture, cure, and testing.	Needed for the bioburden estimate to be performed in support of compliance with PP requirements.
PP certification prior to delivery	The payload provider shall prepare the PP certification form and receive approval by the project PPE prior to delivery.	Needed to maintain an acceptable cleanliness level and provide final component information needed in support of compliance with PP requirements.

Planetary Protection Requirement Short Description	Anticipated Europa Lander Requirement/Constraint	Additional Comments relevant to Instrument Proposers
System I&T surface cleanliness	Exposed surfaces of flight system components shall be maintained at a biological cleanliness level compatible with the mission. [Value TBD]	Needed to maintain an acceptable cleanliness level in support of compliance with PP requirements.
System I&T purge cleanliness	All purge gases used during integration, testing, and launch operations shall be filtered through a HEPA filter and all downstream purge lines shall be sterilized before use to a maximum bioburden density compatible with the mission [Value TBD].	Needed to prevent recontamination during assembly, testing, and launch to maintain the bioburden level needed in support of compliance with PP requirements.
System I&T environment cleanliness	The Europa Lander Project shall maintain assembly and test environments at or below the levels specified for an ISO 7 cleanroom during System I&T.	Needed to maintain an acceptable cleanliness level in support of compliance with PP requirements.
PP integrity not compromised by instrument calibration	Pre-flight instrument calibration activities shall not compromise the biological cleanliness of the flight system.	Payload calibration processes shall be planned to maintain flight system bioburden
Organic materials inventory	The Europa Lander Project shall provide an inventory list of bulk constituent organic materials for all launched hardware as part of the PP Pre-Launch Report.	The Europa lander Project needs to receive from each instrument team documentation of the bulk organics materials inventory for delivered hardware at Instrument CDR.
Organic materials archive	The Europa Lander Project shall collect samples of at least 50 g of each organic material type for which more than 25 kg is transported to the Jovian system, no later than Launch + 30 days for archiving.	The Europa lander Project may request samples of specific materials on the Organic Materials inventory list from instruments to be delivered to the project, no later than instrument delivery to JPL.
Bulk material proxy samples	Payload providers shall provide a proxy sample of all bulk non-metallic materials for destructive bioassay sampling. The material sample shall represent at least 10% by volume of the amount present on the spacecraft.	Needed to develop the flight system bioburden estimate in support of compliance with PP requirements.
Identification of organic materials	The Materials Identification and Usage List (MIUL) for each instrument and subsystem shall identify organic materials by chemical class, manufacturer's part number, and application in use, together with estimated masses.	Provides organic materials information needed to produce the organic materials inventory.
Venting through HEPA filters	All flight system enclosures requiring venting at launch shall be fitted with a HEPA filter (with the vent path through the HEPA filter), or with an alternative protection method acceptable to the Project PPE.	Needed to prevent recontamination of interior surfaces during assembly, testing, and launch to maintain the bioburden level needed in support of compliance with PP requirements.
Pre-integration cleanliness	Assemblies shall meet the biological cleanliness requirements as per the Planetary Protection Plan prior to integration into higher level assemblies and/or delivery to System I&T.	This plan contains the microbial reduction process(es), including process parameters, agreed upon between the hardware owners and the Project PPE.

Table 3-9. Example PP Data Requirements; Europa Lander Payload Data Requirements will be developed during Phase A.

Payload Data Requirements List										
Item No.	**Title or Description of Data**	**APPR Code**	**Frequency of Issue**	**Date due to JPL**	**Project Phases**					**Remarks**
					A	**B**	**C**	**D**	**E**	
	Inputs to Planetary Protection Documentation									
01	Planetary Protection Plan Inputs									
01A	Preliminary Instrument Planetary Protection Implementation Plan	X	Once	IPDR +2 mo.		X				Deliverable Item IPDR; Engineering Submittal

Payload Data Requirements List

Item No.	Title or Description of Data	APPR Code	Frequency of Issue	Date due to JPL	Project Phases					Remarks
					A	B	C	D	E	
01B	Baseline Release Instrument Planetary Protection Plan	X	Once	ICDR +2 mo.			X			Deliverable Item ICDR; Engineering Submittal
02	Planetary Protection Equipment List									
02A	Preliminary Planetary Protection Equipment List (Enumerates instrument component surface areas and encapsulated volumes.)	X	Once	IPDR +2 mo.		X				Deliverable Item IPDR; Engineering Submittal
02B	Baseline Release Planetary Protection Equipment List	X	Once	ICDR +2 mo.			X			Deliverable Item ICDR; Engineering Submittal
03A	Preliminary Organic Materials Inventory	X	Once	IPDR +2 mo.		X				Deliverable Item IPDR; Engineering Submittal
03B	Baseline Release Organic Materials Inventory	X	Once	ICDR +2 mo.			X			Deliverable Item ICDR; Engineering Submittal
04	Planetary Protection Hardware Compliance Report	X	Once	IDR +1 mo.				X		Deliverable Item IDR; Engineering Submittal

3.15.2 Recontamination Control

Recontamination control is key to maintaining cleanliness to the level required for the spacecraft to meet microbial cleanliness requirements at Europa and required as part of NPR 8020.12D (see section 2.3.1.d):

After ground-based bioburden reduction processing, any activity conducted on the instrument—including calibration and alignment checks—that will expose the interior of the instrument to contamination shall be identified, and procedures for repeat bioburden reduction (reprocessing) shall be developed. Steps taken to prevent subsequent recontamination should include specialized handling procedures, seals, covers, filters, and/or other techniques such as those mentioned above. Should an instrument need to be reworked post-delivery, reprocessing may be needed depending upon the level of disassembly. Other important factors that instrument providers should consider for managing recontamination during rework include:

- Ensuring that all H/W elements—independent of the number of boxes—are discrete physical elements with identified bioburden reduction process compatibilities.
- Protecting instrument apertures without windows, or with windows unable to withstand alcohol wipe cleaning or VHP, by a biobarrier, flight covers, or removable preflight covers.
- Implementing post bioburden reduction processing calibration and alignment check scenarios that either do not require or minimize open apertures; e.g., internal or wireless calibration.

Use of HEPA filters shall be compatible with bioburden reduction and allow for venting at launch. Tortuous paths may be allowed as a recontamination control method, upon review by the project.

3.15.3 Planetary Protection Instrument Design Considerations

Instrument compatibility with bioburden reduction processes is critical. This requirement may influence the choice of sensor technology for some instruments if one sensor choice is significantly more robust than another in this context. Instrument providers are also expected to utilize the projects Preferred Parts and Materials List, and should design for bioburden-reduction process compatibility and recontamination control at higher levels of assembly. Providers should keep the following design considerations in mind:

- Payload elements external to the Lander vault are required to be compatible with alcohol (isopropyl alcohol or ethanol) wipe cleaning and VHP treatment.
- Attention should be paid to mechanical and electrical interface designs to ensure issues associated with connectors and enclosures do not compromise recontamination control.
- Connector savers (pigtails) should be considered to maintain the cleanliness of flight connectors during testing with ground support equipment.
- Enclosures (“closed boxes”) may be needed around the instrument to meet recontamination control and radiation shielding requirements, having instrument mass, venting and thermal management implications. Thermal coating choices should not impact the cleaning and bioburden-reduction process compatibility.

By the instrument PDR, the payload provider team should demonstrate compatibility with the bioburden-reduction techniques negotiated with the Project.

4 DELIVERABLES, V&V, AND POST-DELIVERY SYSTEM INTEGRATION AND TEST

4.1 Hardware and Software Deliverables

The following sections identify instrument delivery items for the Europa Lander Project. As described in the following sections, instrument teams are expected to:

- Provide the models described in Section 4.1.1 to support system level simulation, modeling and analysis.
- Provide the hardware described in Section 4.1.2 that meets Project and investigation requirements.
- Provide the software described in Section 4.1.3 that meets Project and investigation requirements.
- Provide or contribute to all required documents, as discussed in Section 4.1.4

Table 4-1 provides a checklist of expected instrument deliverables to System Integration and Test (SI&T) for Flight HW and the System Testbed (STB) for EM HW.

Table 4-1. Instrument Deliverables for System Testing

Type	Description	Delivery to:
Hardware / Software	Flight Model Instrument and associated harness (if instrument consists of multiple units)	SI&T
Hardware / Software	Flight Spare Instrument and associated harness (if instrument consists of multiple units)	Bonded Stores
Hardware / Software	Engineering Model Instrument and associated harness (if instrument consists of multiple units)	STB
Hardware	Prototype Sample Transfer Front End	Sampling System
Hardware	Red Tag/Green Tag Hardware (Hard covers, Soft covers, biobarriers or other sealed enclosure, Connector Savers, etc.)	SI&T
Hardware	Instrument ancillary HW that requires separate installation in ATLO	SI&T
EGSE	Acceptance testing rack or support equipment	SI&T
EGSE	Harnesses to Instrument EGSE rack	SI&T
EGSE	Support equipment for calibration or stimulation	SI&T
MGSE	Lifting Fixtures	SI&T
MGSE	Shipping Containers flight hardware	SI&T
MGSE	Shipping Containers EM hardware	STB
MGSE	Shaker Table Fixtures	SI&T
Simulations	Simulated real science data files	STB
Simulations	Electrical/Thermal Mass Simulators	SI&T
Documentation	instrument model functional specification as input to the project's Workstation Testset (WSTS) flight software simulator	STB
Documentation	Support Equipment Handling/Operations constraint document	SI&T
Documentation	Hardware Review Certification Record (HRCR)	STB and SI&T
Documentation	Support Equipment Certification Record (SECR)	STB and SI&T
Documentation	Circuit Data Sheets (CDS), grounding and cabling diagrams	System Engineering
Documentation	Instrument Drawings	System Engineering
Documentation	Flight Handling/Operations constraint document	STB and SI&T
Documentation	Contamination Control Certification	SI&T
Documentation	Planetary Protection Certification	SI&T
Documentation	Mass Properties Certification	SI&T

Type	Description	Delivery to:
Documentation	As-built Parts List	QA
Documentation	Material Identification Usage List (MIUL); Materials and processes data	QA
Documentation	Test As You Fly (TAYF) exceptions	V&V
Documentation	Instrument Cleaning and handling guidelines	STB and SI&T
Documentation	Instrument/Payload Verification Plan	Systems Engineering
Documentation	Instrument/Payload Functional Test Procedures	Systems Engineering

4.1.1 Simulation

The instruments teams will be required to support simulation in three areas which should be accounted for in the proposals. First, the software simulator, WSTS, will require a command/response-level functional model for each instrument. WSTS is used initially as a test environment for Flight Software development, and then later in the project lifecycle used to checkout test procedures prior to running on testbeds or flight spacecraft in ATLO. Second, System Testbeds (STBs) will need a simulated real-data file providing flight-like command responses and telemetry that can be played back through flight system and ground system to provide an early check of the end-to-end data flow. This simulated real-data file will be used in some tests as a replacement for the instrument data return in configurations that lack instrument hardware. Third, system integration and test (SI&T) will need an Electrical/Thermal Mass Simulator as a contingency in case an instrument is not available, (e.g., due to damage) either prior to environmental testing or later.

4.1.2 Early Electrical Interface Tests

4.1.2.1 Post-IPDR loan of Lander Avionics Breadboard

A spacecraft 'suitcase' emulator will be made available on loan from the Project to the instrument teams shortly after PDR (see Table 9-2 for schedule) for spacecraft/instrument hardware and software interface testing and verification.

4.1.2.2 Pre-ICDR loan of Instrument Electronics Breadboard

A short-term loan of Instrument Electronics Breadboard hardware to support early electrical and protocol tests and a preliminary electrical interface checkout test against a representative system-level interface will be required; for example, a plug-compatible breadboard, prior to I-CDR (see Table 9-2 for schedule). The duration of the loan is expected to be on the order of several days. This unit may be used with the payload checkout bench or developmental lander system hardware. The interface to the spacecraft must be functionally identical to the flight unit. Instrument team support of this test activity is required at JPL for up to 1 week.

4.1.3 Hardware Deliverables

Table 4-3 provides further description of the major Payload hardware deliverables to the Project

Table 4-2: Major Payload Hardware Deliverables

Hardware Element	Description
Flight Model (FM)	Instrument hardware element to be flown
Flight Spare	Backup instrument equivalent to the Flight Model, to be available for substitution into the spacecraft and flight in the event of technical difficulties with the Flight Model

Hardware Element	Description
Engineering Model	Non-flight hardware equivalent to the FM hardware in form, fit, and interface functions (electrical, data, sample handling). The EM will be integrated into the System Testbed Lander and used for development and dry-run of procedures to be executed on the FM in ATLO, elements of V&V (particularly sample-transfer and off-nominal scenario tests not run on the flight spacecraft), and Operational Readiness Tests. The EM need not be capable of full science-quality measurements, but the interaction with Lander FSW should be flight-like with realistic command execution delays, generated data volumes, etc.
Prototype Sample Transfer Front End	Non-flight mechanical hardware that receives sample from the Sample System. This hardware element will be integrated into the Sampling System testbed for use in sample transfer testing at both ambient and Europan environmental conditions (cryogenic vacuum). This prototype should include any actuators and sensors associated with sample transfer and be accompanied by EGSE required for control. The initial use for this hardware element is developmental testing and risk reduction, and as designs solidify this prototype should be refurbished to match the final flight configuration. This hardware element will also be used in flight to support any necessary troubleshooting of sample transfer during surface operations

An End Item Data Package (EIDP) should be provided with each hardware model delivery and the Ground Support Equipment (GSE). If only one GSE unit supports both the EM and Flight Model (FM), it should meet the flight interface specifications.

4.1.3.1 Engineering Model

The engineering model (EM) shall be part of the instrument design development and qualification process. The EM is non-flight hardware equivalent to the FM hardware in form, fit and function. The EM will be integrated into the spacecraft system testbed. Any GSE needed to maintain the health of the EM (e.g., cooling) should be provided. The EM shall provide electrical, timing, and protocol interfaces that are identical to the flight instrument, be compatible with a clean room environment, and be capable of being stimulated to provide operational data and representative data sets to exercise the Mission Operations Systems (MOS).

The EM must include flight-like sample transfer front end, including any processing / transport of sample internal to the instrument in order to enable end-to-end sample acquisition/transfer tests at ambient environment (with sample simulants). For the CRSI, the EM will need to be capable of providing images that support engineering functions, e.g., workspace imaging and DEM generation, for both Lander Verification testing and Operations Readiness Testing. Science-quality measurements from EM are not required, and therefore it is expected that the EM may be missing some internal components. Proposals should specify what subset of the flight design is planned to be excluded from the EM, with rationale. .

The EMs may be returned to the instrument team for refurbishment to match any configuration changes made on the FM instrument subsequent to the initial EM delivery. The refurbished EM shall be redelivered to the Project to support post-launch operational tests. The EM shall remain with the spacecraft testbed during mission operations and will not be returned to the payload provider until the mission is complete.

EM instruments typically do not have the pedigree and the cleanliness and sterilization to be integrated to the Flight System as a contingency action. Instrument Engineering Models will not be integrated with the Flight System. If a contingency is required as a result that an instrument is not available for SI&T on time, the project will require an Electrical/Thermal Mass Simulator to be delivered to SI&T for integration with the Lander to support SI&T Environmental testing.

4.1.3.2 Flight Model

The FM should successfully complete all acceptance or protoflight functional, performance, environmental testing, calibration and required Planetary Protection microbial reduction prior to delivery and integration with the flight spacecraft. The instrument shall be accompanied by all electrical and mechanical GSE needed for shipping, handling, contamination control, stand-alone testing, integration and system testing (including optical and thermal calibration targets and other specialized equipment), and launch operations. All test cables and any protective non-flight covers are included with the flight hardware delivery.

The flight unit, or FM, hardware must meet all the requirements contained in the FRD and ICDs, as well as reliability and mission assurance requirements. The FM will be integrated with the flight system. The accompanying GSE must contain all hardware and software required for maintaining the health of the flight unit and for providing stimulation and testing. Prior to the FM payload science instrument integration, all instrument-level GSE will be the responsibility of the PI. Any anticipated instrument-unique accommodation elements should be described in the proposal.

Schedule and delivery milestones indicated in this PIP reflect integration readiness requirements. Actual instrument hardware delivery dates must allow for any instrument-required pre-integration activities, as well as adequate time to accomplish bench acceptance test at JPL post-delivery. A dedicated payload bench acceptance test lab will be provided at JPL that meets SI&T cleanliness and ESD controls, etc. Cabled interface separation between payload bench acceptance test lab GSE room and the Flight hardware may be as long as 15 meters. If GSE interfaces aren’t compatible with this separation, the flight EGSE may need to be cleanroom compatible.

4.1.3.3 Flight Spare

Instrument teams shall provide a fully integrated and tested flight spare. This will allow rapid replacement of the flight model in the event of a post-delivery failure or anomaly. The spare will be retained at the instrument team’s home organization until required by the Project. If the spare is required, it should have completed all performance, functional and environmental testing, calibration and the necessary planetary protection microbial reduction prior to delivery.

4.1.4 Software

The spacecraft compute element will provide command forwarding and telemetry/data storage services. Any instrument data processing or autonomous responses shall be run in the instrument software. Instrument software running on the EM or the FM shall be provided with each hardware delivery. Instrument flight software should be developed in accordance with an instrument Software Development Plan.

4.1.5 Documentation

There are various forms of documentation needed by the project. Several of these documents are due at the time of hardware delivery to SI&T and STB.

First, Quality Assurance (QA) conducted by the delivering organization will perform a delivery inspection. Any discrepancies will be documented in an Inspection Report (IR).

Second, all flight hardware deliveries must be accompanied by a Hardware Review Certification Record (HRCR) form. All support equipment must be accompanied by a Support Equipment Certification Record (SECR) form. The HRCR checks on completeness of the following:

- drawings and specifications

- compliance to all Project payload requirements via Requirements Verification Matrix
- requirements verification and validation data
- List of waivers, PFRs, and ECRs
- inspection reports
- as-built parts list
- EM vs. FM difference list
- review of action items
- Shortage List
- required analyses
- environmental tests and analyses
- GIDP Alerts
- software (SRCR)
- telemetry calibration data
- archive plan
- TAYF exceptions
- compliance with contamination control
- compliance with Planetary Protection
- procedures provided to SI&T
- list of items to be removed/installed prior to I&T and/or launch
- Instructions for safe handling, cleaning and other contamination control procedures, testing, operating, packaging, storage, and shipping.

Third, Quality Assurance (QA) will perform a receiving inspection for each instrument delivered to SI&T. QA will review the following:

- instrument drawings
- Flight Hardware handling/operations constraint document
- contamination control certification
- planetary protection certification
- mass properties certification
- as-built parts list
- materials and processes data.

QA will document any discrepancies in the HRCR document or visual inspection in an inspection report (IR). The visual inspection will look for items such as nicks, cuts, scratches, tears, etc., and any indication that the hardware was damaged during transportation. All critical IRs must be dispositioned by QA prior to releasing the instrument to SI&T.

Nominally, JPL suggests that each instrument team provide adequate support to close out HRCR and IR action items quickly. Each instrument team should provide 30 days' support prior to instrument delivery at HRCR to SI&T.

4.2 Instrument Verification and Validation

Verification and Validation (V&V) is required to provide evidence that an instrument (along with the flight system as a whole) meets its objectives and constraints. V&V is an integral part of mission architecting, so it should be started early and carried across the Project lifecycle. The Project intends to develop verification plans in parallel with requirements to ensure clear meaning and timely V&V capabilities. The V&V process will address design of the system, quality of implementation, veracity of architectural assertions, viability of operational plans and scenarios, and credibility of models and analyses. Proposals should specify any special tests required and/or constraints imposed upon the post-delivery system integration and test plan.

V&V can be accomplished through testing, analysis, inspection, demonstration, or simulation. All of these options should be considered for use in each specific case. It should be recognized that most tests have some non-flight-like aspects, and other V&V methods have similar deficits. Therefore, how the results of V&V are collectively extrapolated to flight conditions should be understood and well addressed. Instrument teams should plan stress tests beyond nominal operating parameters.

The principle of "Test-As-You-Fly" (TAYF) means that ground tests and simulations should accurately reflect the planned mission profile, plus margin and the appropriate off-design parameters. The "Test-As-You-Fly" principle is a key test philosophy to be factored into the test program definition of a product's life cycle to ensure mission success. The basic principle is "No function, environment, or stress should be experienced by a product for the first time during its mission."

V&V can be broken down into the following categories:

- Functional — Functional V&V covers all the capabilities of a system and investigates the relationships among system elements. The Project intends to establish V&V criteria according to modeled predictions and devote ample time for model validation.
- Fault Tolerance — Fault tolerance covers normal functions, and provisions for fault injections, diagnostics, and other aids in supporting tools starting early in the lifecycle.
- Environmental — Environmental V&V considers environmental tests and analyses that verify the design's tolerance to plausible environmental conditions. These efforts should include attention to items traditionally considered separately such as parts and materials characterization.
- Operational — Operational V&V addresses the expression of system functions throughout various system states and transitions with emphasis on critical events and key scenarios. In this respect, the Project intends to thoroughly explore variations or demonstrate tolerance for variations in V&V efforts.

Instrument teams should consider using "pathfinders" such as prototypes or engineering models for practice and experimentation (e.g., planetary protection bioburden reduction procedures), as appropriate, to ensure successful integration. The Project shall require instrument teams to demonstrate survivability after three cycles of the dry heat microbial reduction (DHMR) process, including assay verification of bioburden reduction, as well as post-DHMR instrument calibration and alignment checks to verify functionality.

The Europa Lander Environmental Requirements Document (ERD) describes the tests and analyses that should be completed to ensure survivability in the relevant environments for the Europa Lander mission. The environmental design and verification program is intended to demonstrate through design, test, and/or analysis methods, the ability of the Europa Lander flight system, including instruments, to successfully withstand and/or operate in the specified ground, transportation, storage, launch, and mission environments. The document also describes the implementation, control, and reporting policies for environmental testing of Europa Lander flight or qualification hardware.

4.3 Post-Delivery System Integration and Test

4.3.1 Integration and Uses of the Engineering Model Instruments

EM instruments will be integrated into the Europa Lander System Testbed (STB), a flight-like testbed that includes, electrical interface checks, functional testing with Project-provided GSE, and flight software checkout. The testbed shall have high fidelity, flight-like interfaces and be capable of commanding science payload instruments with the flight and ground software while using the system data bus; it can also collect telemetry. Functional and system-level tests will be performed in this configuration.

Instrument team support will be required for development of the procedures for integration and testing on the system testbed. Instrument team support will be required during the actual integration of the science instrument into the system testbed, and V&V involving that instrument within the system testbed. Integration activities start shortly after EM delivery and continue for approximately 2 months. During this period, the integration of each instrument may require approximately 10 days total time of intermittent instrument on-site support. This is an estimated time based on a “typical” integration; actual times required by specific individual instruments may vary.

System tests using the EM instruments will be conducted throughout the months following system testbed integration. Instrument team support for these tests will be scheduled, and instrument teams will need to be alerted as to their frequency, duration, and nature. System-level instrument functionality V&V will be carried out within the testbed environment, except in specific cases where functionality can only be proven on the flight equipment. System V&V within the testbed consists of scripted tests conducted by trained test conductors and systems engineers, along with instrument team support. These tests may require some level of support either remotely or on-site. Instrument teams will be notified in advance of these tests. Instrument teams should anticipate 10 days of intermittent on-site support and 4 months of remote support during this period.

EM instruments will remain in the System Testbed until the end of mission as a part of the Europa Lander mission operations testbed, apart from any required rework and redelivery back to the Project (e.g., to match FM).

4.3.2 Integration and Test of the Flight Model Instruments through SI&T

Each FM instrument is integrated using assembly plans and test procedures that ensure mechanical and electrical safety and which have been verified in the testbed. Instrument teams are responsible for providing inputs, plans, procedures, execution monitoring, troubleshooting, and post-test analyses for system-level tests involving the relevant instrument.

Instrument electronics shall be required to accumulate 300 hours of functional operation prior to delivery for system I&T and an additional 200 hours during system testing, for a total of 500 hours prior to launch.

In Phases C and D, the Flight system will be subject to a variety of tests. Table 4-3 provides a definition of typical tests provided at the system and subsystem levels performed at JPL. Instruments are expected to complete all subsystem testing prior to delivery to SI&T for system testing. System-level test will be used to assess all engineering assemblies and instruments at the system level either using the hardware testbeds or during SI&T activities.

Table 4-3. Europa Lander Test Definitions

Test	Description	Typically System Tests
Baseline Test	A set of functional verifications will be designed as a regression test to determine that the hardware functions as expected. This test will be periodical rerun to detect if an anomaly occurred as a result following a major event in the SI&T flow	Yes
Abbreviated Baseline Test	Shortened Verification. Used between rapidly repeated tests such as Vibration testing	Yes
Functional Test	Functional testing covers the full range of capabilities of the unit under test	Yes
Touch Test	Testing to identify a response or aliveness to a given stimulus	Yes
Phasing Test	Testing to verify end-to-end the mapping from commands and telemetry channels to direction conventions or to identical elements within an instrument or subsystem	Yes
Bench Acceptance Test	Formal delivery testing conducted to determine whether a system satisfies the acceptance criteria and to enable the user, customers or other authorized entity to determine whether or not to accept the system.	Yes
System Test	A program or control sequence will be used to check system requirements. Sub classifications include: Mission Sequence Test, Operational Readiness Test, System Verification Test, End-to-End Information System Test	Yes
System Environmental Test	Includes: Acoustic Noise Test, Random Vibration Test, Pyroshock Test, Structural Loads Test, Modal Test, EMC Test, Magnetics Test, System Thermal Test	Yes
Regression Test	A type of software testing that verifies that software previously developed and tested still performs correctly after it was changed or interfaced with other software. (Primarily used in STB)	Yes
Electrical Integration Procedure (EIP)	After the mechanical installation, the electrical integration of an assembly or device will be checked. The first step will be a power off measurement of each pin in the interface connector. The second step will be a power on measurement of each pin in the interface connector. Once the circuits are verified, the test engineer will mate the interface connector and perform a short functional check. This procedure is also called Safe to Mate (S2M)	Yes
Stress Testing	Testing Peak activities over a short span of time	No
Load Testing	Testing for largest load/capacity handled at one time	No
Volume Testing	Testing heavy volumes of data over time (combination of Stress Testing and Load Testing over time)	No
Performance Testing	Tests user response time	No

4.3.2.1 Integration of the Flight Payload Instruments

After the delivery of each payload instrument, and prior to integration onto the spacecraft, each instrument should pass a stand-alone bench acceptance test to verify the health of the delivered instrument. Instrument hardware delivery dates need to accommodate any instrument-required pre-integration activities, such as an HRCR, as well as adequate time to accomplish stand-alone bench acceptance test. Schedule and delivery milestones indicated in Figure 4-1 reflect SI&T integration readiness requirements.

Instrument SI&T will start with the mechanical installation and electrical integration of flight instruments with the spacecraft. Instrument/spacecraft integration activities may require on-site support from the PI, or members of the instrument development team, and/or project instrument engineers. Dates for support will depend on actual instrument delivery dates and SI&T dates for instrument integration to the spacecraft.

4.3.2.2 Spacecraft Functional Testing

Following spacecraft assembly and checkout, functional tests will be conducted on the flight spacecraft. These tests are based upon a V&V matrix of requirements and consist of tests aimed at proving out the system requirements.

Functional tests using the FM instruments will be conducted throughout the SI&T flow as shown in Figure 4-1. On-site or remote instrument team support for these tests is necessary. Instrument teams should anticipate 20 days of on-site support (which may be discontinuous) and 1 month of remote support during this period.

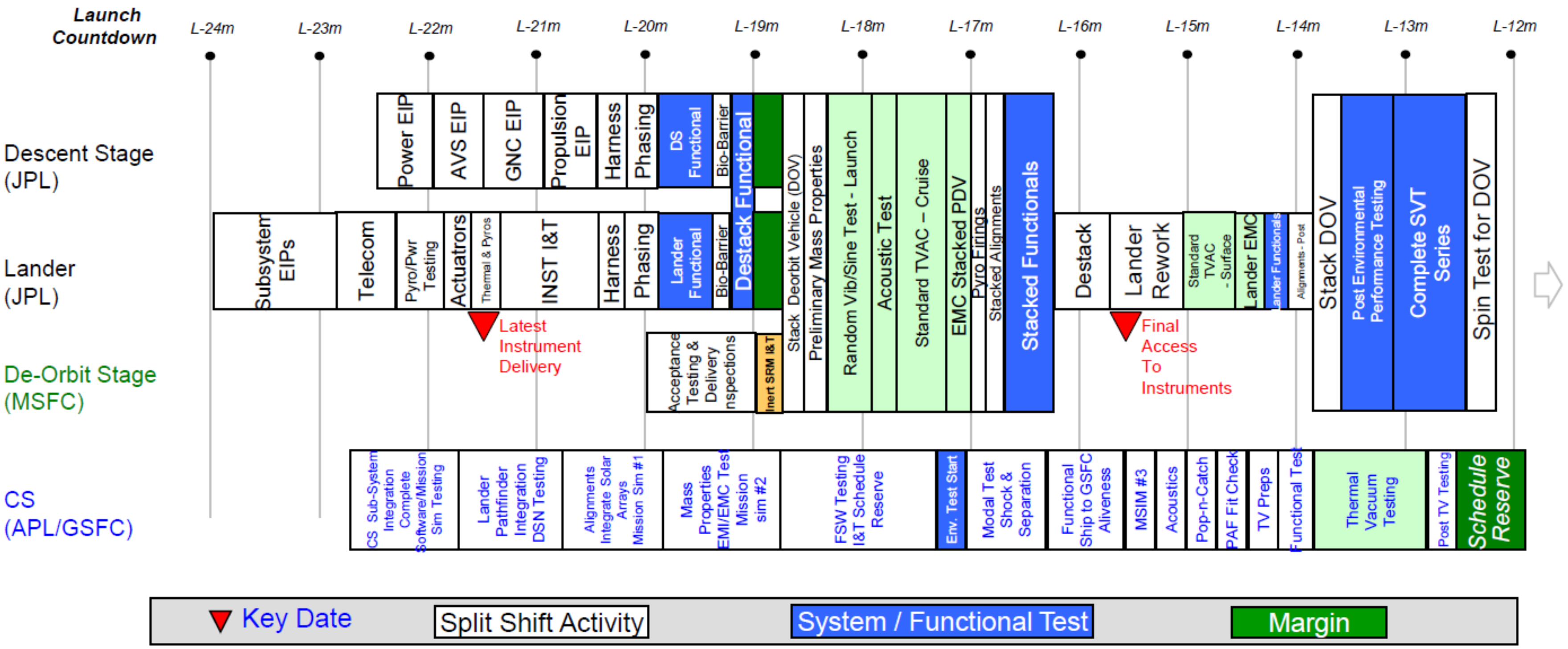

Figure 4-1. Europa Lander SI&T Overview – Pre Ship

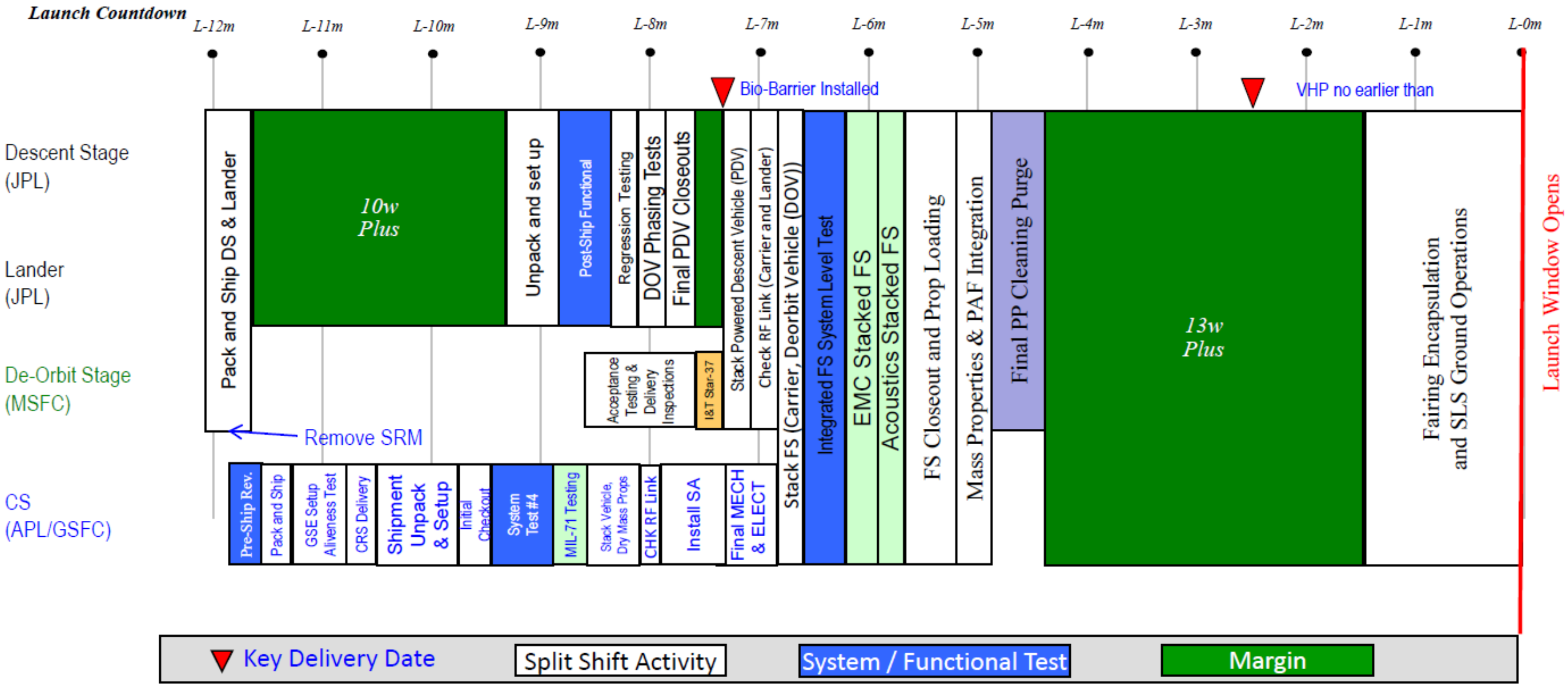

Figure 4-2. Europa Lander SI&T Overview - Post-Ship

4.3.2.3 System Environmental Tests

System-level environmental tests are performed in accordance with the Europa Lander ERD. System-level environmental tests include system level acoustics, vibration and shock, thermal balance, and thermal vacuum. The system level EMC/EMI, and magnetic cleanliness verification are performed via a combination of testing and modeling of the assembly and subsystem level testing performed prior to SI&T. Functional tests are repeated after each environmental test to ensure that the test effects have not degraded system performance. Post-environmental tests also facilitate verification of any modification to flight software or flight sequences. The tests are listed in Table 4-4.

Table 4-4. Europa Lander Configurations for Environmental Testing at JPL

Environment	H/W	Configurations
Random vibration	PDV	Launch – Stowed
Acoustic	PDV	Launch – Stowed
Standard TVAC cruise	PDV	Launch – Stowed
EMC, stacked configuration	PDV	Launch – Stowed
Pyro shock	PDV	Launch – Stowed
Standard TVAC lander surface	Lander	Surface – Deployed
EMC deployed	Lander	Surface – Deployed

These tests include instrument operations and may require support from the PI or members of the instrument development team, and/or project instrument engineers.

4.3.3 System Tests

Throughout SI&T there are opportunities to conduct tests of the flight system using the ground system and mission operations system procedures. These flight-like tests draw on operations personnel to “fly” the spacecraft in a configuration that mimics flight for all mission phases.

SI&T system engineers will perform all testing with support from subsystem and instrument engineers and the operations team. Instrument operators will participate in these tests and follow procedures as if the vehicle were post-launch. These are tests of personnel, procedures, and ground equipment as well as flight equipment and software. Instrument team support for ATLO system tests will be scheduled, particular Lander Functional Tests, Lander TVAC and EMI/EMC tests, and post-ship functional tests. Instrument teams will be notified in advance, and should anticipate approximately 15 days of remote support during this period.

4.3.4 Instrument Constraints

The post-delivery tests identified above may present problems for some instruments. Each instrument will need to identify operating constraints in ambient and during environmental testing. Each instrument must identify its specific list of SI&T constraints. The following questions are examples that may constrain testing:

- Does the instrument include cover(s)?
- Is there a minimum vacuum level needed prior to turn on?
- Is there a constraint to not expose above a specific humidity?
- Is there purge outage duration (with and without a cover)?
- Are there any Red Tag (Remove before flight) or Green Tag (Install before flight) items associated with the instrument?

- Will there be any GSE supplies with the instrument?
- Will there be any GSE that interfaces with the instrument?
- Is there support equipment needed to support testing?
- Is there any need to access instrument after final planned access time (Lander rework opportunity)?

4.3.5 Kennedy Space Center Operations - Prelaunch Phase

The spacecraft will be shipped to Kennedy Space Center (KSC). Following setup and post-shipment checkout activities, the final suite of pre-launch functional tests are executed (see Figure 4-2). These tests are aimed primarily at regression-testing the flight vehicle and flight software. The Lander will be in its final stowed configuration, and physical access to instruments may be constrained or non-existent. Instruments should be designed to minimize or eliminate any requirements for external access, e.g., inclusion of internal calibration targets, pin out test data ports to an accessible external cable bulkhead, etc. Final system-level DHMR and/or VHP processing may occur at KSC.

Except for any special closeouts and support of final functional tests by remote access, instrument team support is not expected to be required during the SI&T prelaunch phase.

5 MISSION SCENARIOS

This section summarizes the concept of operations throughout the mission, highlighting high-level constraints on instrument operations.

5.1 Pre-launch, Launch and Spacecraft Commissioning

Proposals must identify any instrument-related activities that must be accommodated during the pre-launch phase; for example, required purge operations, system-level calibration activities, removal of “red tag” remove-before-flight items, or any hardware that requires late installation at KSC (as identified in response to questions posed in section 4.3.4).

All science instruments will be launched in a powered-off state, and no science instrument activities will be planned during the launch phase.

After confirmed, successful completion of the launch sequence including separation from the launch vehicle, commissioning operations will begin. The overall commissioning goals are to (1) verify health, safety, and basic functionality of spacecraft and instrument components in the space environment, (2) perform the first trajectory control maneuver (TCM), and (3) demonstrate all spacecraft, instrument, and ground system functionality required to support inner solar system cruise. Proposals should identify the type of instrument initial checkout activities requested

5.2 Interplanetary Cruise

The Europa Lander architecture includes neither accommodation for externally mounted instruments during cruise nor provision for Lander-mounted instrument access to the outside environment during this phase.

Details of the trajectories and interplanetary cruise options are discussed in Section 2.1. Instrument health check activities will be scheduled during cruise, ensuring that the instruments are in their expected state at the start of the surface phase. Instrument checkout activities are anticipated twice a year and after any critical event. No provision for cruise science is anticipated. During quiet periods of the cruise phase, the operations teams will be testing and training with the tools and processes to be used for Europa surface operations (see Section 6.5)

5.3 Jupiter Orbit Insertion (JOI) and Jovian Tour

There will be no instrument activities during the JOI maneuver.

Post-JOI, a significant fraction of the total mission radiation dose is expected to accumulate during this phase, as described in the Environmental Requirements Document (ERD). Final instrument checkout activities will be scheduled to ensure that the instruments are in their expected state by the start of the surface phase.

No instrument science activities are anticipated during this period.

5.4 Deorbit-Descent and Landing

No instrument operations are expected during DDL and instruments will remain powered off. The instruments will be functionally and, perhaps, electrically isolated to remove the possibility of interference (for discussion of grounding, see Section 3.7.2)

5.4.1 Transition Phase

The transition phase is the brief period after landing needed to perform critical deployments and spacecraft calibration. Deployments include the Lander stabilizers, release of the sample system bio-barrier and arm, and deployment of the CRSI and high gain antenna. The entire surface transition phase is expected to take approximately 15 minutes, be fully autonomous, and will complete by establishing the return of data to Earth via the high gain antenna. Immediately following the transition phase, the surface phase begins, including the first surface activities for all instruments.

5.5 Surface Phase

The surface phase is the phase of the Europa Lander mission for science activities, planned for a duration of at least 20 (Earth) days, during which time the Lander is expected to complete at least three sample acquisitions (see Figure 5-1). Direct-to-Earth (DTE) Communications requires Lander line-of-sight view to the Earth which, in turn, is determined by the 3.5-Earth-day rotation of Europa. The communications pattern is ~1.5 Earth-days of continuous communications opportunity separated by ~2.0 Earth-days of no communications. From the Lander's point of view, the Earth and the Sun are in roughly the same direction, and therefore the Lander is generally in sunlight during the communications periods.

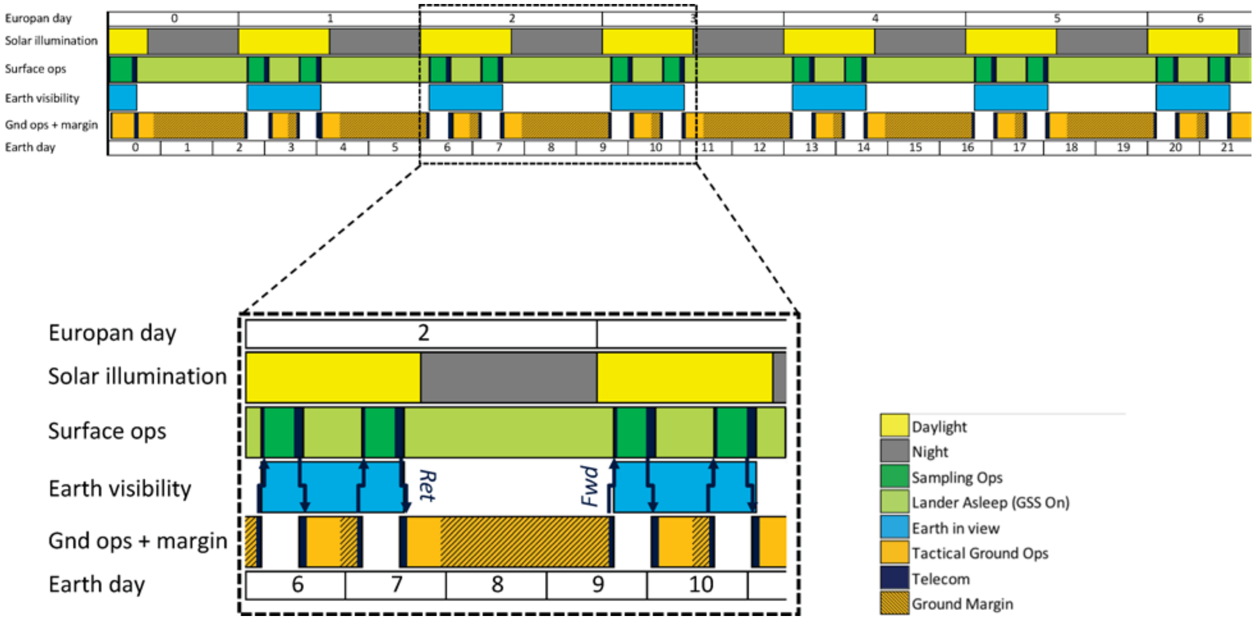

Figure 5-1. Europa Lander Surface Operations Cadence

The cadence of Surface Operations is adapted to the Project's strategy for autonomous operations and the Europa Lander communications pattern. A science Monitoring campaign using the Geophysical Sounding System and the Context Remote Sensing Instrument is executed throughout the surface mission, whereas the Sampling campaign executes primarily during periods with communications. Each full cycle for the operations team begins with the rise of Earth above the horizon at the landing site, at which time the Lander and the Operations Team can communicate. While the Lander continues to execute its activities, key data is returned to Earth enabling ground operators to monitor spacecraft and instrument health, assess progress, and rapidly respond to any unforeseen situations or anomalies. Similar to mission-critical autonomous activities on past missions (e.g., Entry, Descent, and Landing for Mars rovers and landers), intense activities such as sample acquisition, transfer, and analysis are preplanned to execute during these communication periods to maximize situational awareness. After the Earth sets below the horizon and communication is lost, the Lander continues its science activities. In parallel, the Surface

Operations team performs thorough analysis of all received data, compares expected instrument performance and science return against expectations, updates the strategic plan in light of any variances between the original plan and actual Lander execution state, and if necessary produces and verifies uplink products to adjust subsequent Lander activities in the next communications opportunity.

5.5.1 Key Terminology

Table 5-1 defines key terminology for Europa surface operations.

Table 5-1. Europa Lander Surface Phase Key Terminology

Terms	Definitions
Ground planning cycle	The working shift for the operations teams, starting with the receipt of the first bit of return link (telemetry) in the Mission Support Area (MSA), through transmission of the command sequences to the lander. Ground cycles are typically short (6-8 hours) during the Europan day and long (36-48 hours) during the Europan night.
Sampling Campaign	The sampling campaign consists of those activities across the mission that led to the collection, documentation, and analysis of at least three samples from the Europan surface.
Sampling Operation	A sampling operation is a set of commands that contribute to the sampling campaign, executed by the sampling system and/or sample analysis science payloads, grouped together into an autonomous sequence.
Monitoring Campaign	The monitoring campaign consists of remote sensing instrument science activities, i.e., imaging and geophone monitoring, carried out over the course of the surface mission.
Decisional data	Engineering and science data that is critical for decision-making in the subsequent ground planning cycle, e.g., prior activity completion status, instrument health state, summary science analysis results, etc.
Non-decisional data	Data that is not required to feed into decision-making for the immediately following ground planning cycle, e.g., full science analysis results

5.5.2 Landing Day Activities

Immediately after the transition phase, surface phase operations will be initiated. Landing day activities include imaging to help establish spacecraft attitude and characterize the immediate environment, and checkout and calibration of all instruments. Each instrument must autonomously assess its checkout results and report to the Lander flight software that the instrument is ready for science use. After return of these data, the Lander executes a period of monitoring science (geophysical and remote sensing) before autonomously initiating the sample collection, transfer, and analysis activity. During this period of monitoring science activity, the Operations Team has an opportunity to assess the state of the Lander and the Lander's environment to confirm that the spacecraft, the instruments, and the topography in the workspace are within expectations prior to autonomous sampling. In the case where anomalies are discovered outside the range within which the autonomous system can successfully mitigate, the Operations Team has the ability to uplink commands to adjust the onboard autonomous sequence prior to sampling.

5.5.3 Monitoring Campaign

The Monitoring Campaign consists primarily of operating the monitoring instruments, which will be switched on shortly after landing. These instruments will remain on continuously, defining the primary low-power state for the Lander when it is asleep. Data will be periodically transferred or copied from the monitoring instruments to the Lander at least once per Europan day. In addition, the monitoring campaign may occasionally include operation of the imaging instrument to help characterize the Europan environment.

5.5.4 Sampling Campaign

The Sampling Campaign consists primarily of the collection of a series of samples from the Europan surface and the analytical science measurements performed upon those samples. The campaign is carried out via several distinct sampling operations over the course of the mission. Each sampling operation may include some or all of (i) site excavation, (ii) sample acquisition, (iii) sample delivery, (iv) sample analysis by the instruments, (v) return of the sample analysis data to Earth, and (vi) "flushing the system" to dump sample and clear out the instrument to reduce contamination of the next sample to be analyzed. A sampling operation represents the most active period of time on the Lander throughout the mission and several constraints must be taken into account:

1. Thermal: In order to manage the thermal state of the Lander, C&DH must be periodically powered off. As a result, instruments that operate longer than 1 hour must be able to operate without flight software monitoring of the instrument.
2. Autonomy: Each sampling operation is expected to be a fully autonomous sequence of events and performed with no real-time interaction with Earth. Once begun, the sampling operation will go through each of the defined steps, with the sample delivered to each instrument, and each instrument's analysis activities executed to completion. Further, any post-analysis activities required by an instrument to prepare for a next sample need to be accomplished.
3. Data Return Priority: Sample analysis in the instruments can continue after loss of communications, but the autonomous sample analysis sequence should complete an adequate subset of the sample analysis prior to end of the communications period. In particular, enough of the analysis should be completed and downlinked to enable the Instrument team to assess with high confidence the likelihood of successful completion after loss of communications. This approach optimizes the speed with which the Operations team discovers any anomalies or other deviations from expectations in science analysis execution, and maximizes the time available for the instrument team to formulate and execute a response. Such data from sampling analysis returned prior to Earth set is termed *decisional data*, i.e., data sufficient to either confirm satisfactory execution of the preplanned autonomous sequence, or decision to modify future execution.

5.5.5 Ground Planning Cycle

The ground cycle starts with receipt of decisional data transmitted to Earth and ends with the transmission of spacecraft commands from Earth to the Lander. There are two distinct timescales for ground operations. During periods when there is no line of sight between Earth and the landing site, 36-48 hours will be available to complete ground operations, including both instrument command generation and strategic science planning. However, once the Earth rises above the landing site, communication can be reestablished and ground operators will have the ability to turn around command generation at a faster pace. During this period, approximately 6-8 hours will be available on each occasion for the ground operations team to perform data analysis, make decisions, and finalize command products. The scope of instrument commanding during this period is planned to be limited due to the short turnaround time, primarily to perform key decisions best made by the ground team and able to use pre-planned actions that can be finalized quickly for uplink. The ground planning cycle is described in more detail in Section 6.2.2.

5.5.6 Instrument Resource Constraints

The instruments are expected to reasonably operate within the resource envelopes described below. Lander surface operations, for the reasons described earlier, are tightly coupled to the power, thermal, and data resource requirements. Table 5-2 shows the resource allocations for the entire mission.

Table 5-2. Notional Instrument Resource Constraints

Payload-specific metric	Allocation	Rationale
Total science data for baseline mission	600 Mbits	Limit enables completion of baseline mission using lowest anticipated bandwidth
Decisional data volume for documenting/analyzing a sample	50 Mbits per sample	Limit enables short turn around for next command opportunity with adjusted payload settings
Time allowed between instrument power-on and ready to receive sample	60 minutes	Limit energy expended by flight system during instrument initialization
Time for analysis instrument suite to generate decisional data	4 hrs. per sample	Limit enables short turn around for next command opportunity with adjusted payload settings
Time for analysis instrument suite to complete all analyses	10 hrs. per sample	Limit enables reset of the system prior to next potential sample delivery
Instrument ground operations (within same Earthrise period)	6-8 hrs.	Limit allows for assessment/update of instrument parameters for a subsequent use before Earth sets
Instrument ground operations (between distinct Earthrise periods)	36-48 hrs.	Limit ensures that commands are ready for sending to the lander at the next Earthrise
Total Instrument Energy	1600 Whrs (CBE + Uncertainty)	Inclusive of all instruments. Excludes energy for sampling system and engineering use of CRSI
Total Instrument Data Volume	600 Mbits (CBE + Uncertainty)	Inclusive of all instruments. Excludes data volume associated with the sampling system and engineering use of CRSI.

5.5.6.1 Data Acquisition and Storage

The Europa Lander data acquisition strategy involves rapid data collection into onboard storage over a short period of time (a few hours) during each sample activity, followed by an extended period during which data from the geophysical sounding system instrument is collected. The data from analytic, monitoring, and imaging instruments must be partitioned into decisional data and non-decisional data. Total data allocation is shown in Table 5-2. Data will nominally be transmitted at regular intervals and at key events during each communication opportunity. The majority of the data from the Lander is nominally returned to Earth at the earliest opportunity.

6 MISSION OPERATIONS SYSTEM AND GROUND DATA SYSTEM

For the Europa Lander Project, the Mission Operations System (MOS) is defined as the people, procedures, and Ground Data System (GDS) with which the teams operate all aspects of the mission. The GDS comprises the hardware, software, facilities, and infrastructure that the MOS uses to operate both the ground and flight elements of the mission. The MOS includes Project-centralized functions (facilities, teams, and procedures), and distributed functions for the operations of instruments or other specialized needs. Figure 6-1 shows a typical representation of the functions and flow of products among the MOS elements in the Project, as well as interfaces with NASA infrastructure that provide services to the Project, namely, the Deep Space Network (DSN) and Planetary Data System (PDS). The figure is a representative view of the reference concept; specific design details will emerge in Phases A and B.

There is no provision for science instruments on the Carrier spacecraft, and there are no science operations before landing other than instrument checkouts during cruise; thus, the remainder of this section focuses solely on Lander operations.

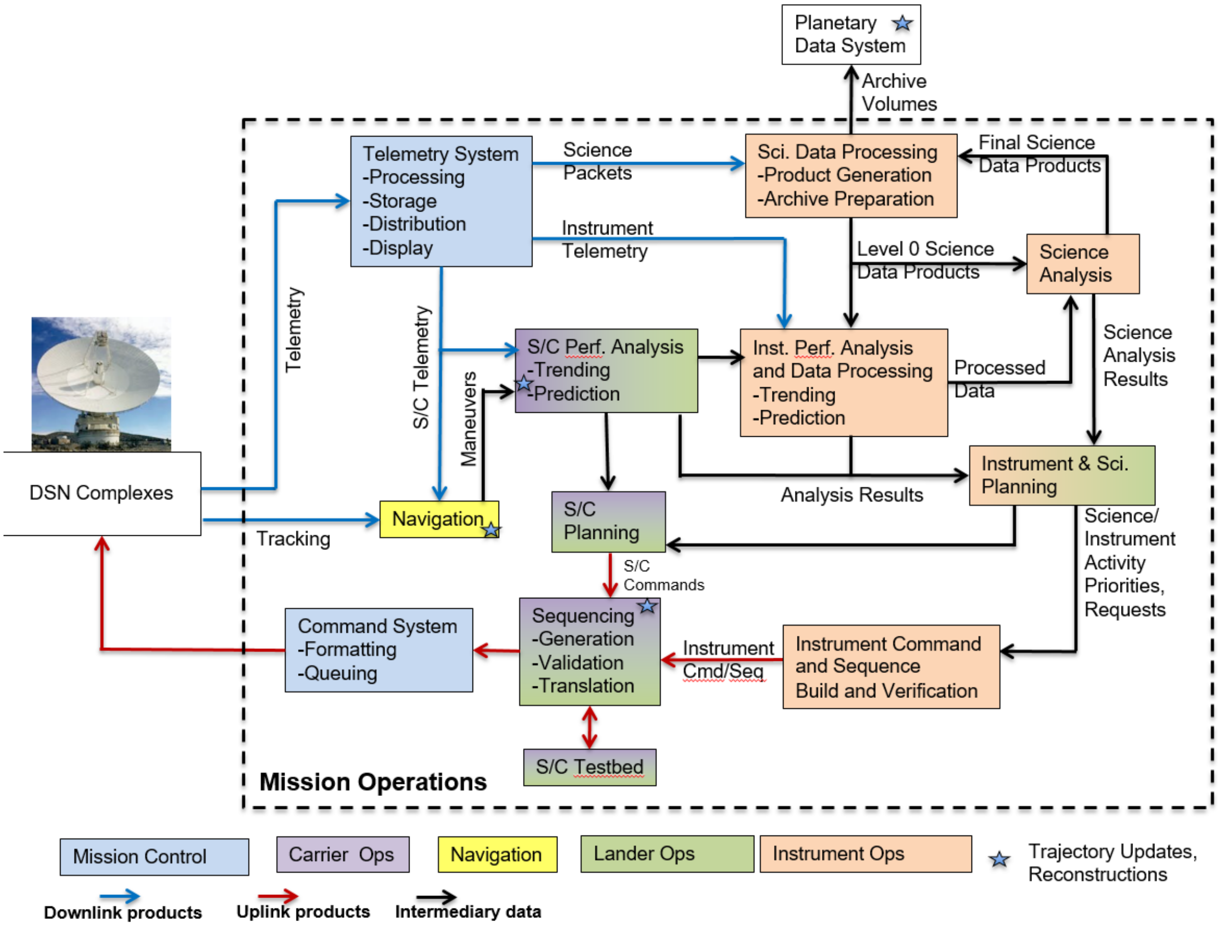

Figure 6-1. Europa Lander Operations Architecture and Data Flow

6.1 MOS/GDS Description

The teams, software, facilities, processes, and procedures for Europa Lander operations will be based on those of successful planetary and landed missions including Cassini, MRO, and MSL, as well as those being developed for Europa Clipper and Mars 2020 (M2020). Personnel will staff the Europa Lander Mission Support Area (MSA) and associated operations support, including navigation and mission planning support, with wide experience in planetary cruise and surface operations.

6.1.1 Teams

All Europa Lander operations teams, including the Mission Manager and the Science Operations Team, will be co-located at the MSA at JPL for surface operations, instrument operations between launch and landing, and operational readiness tests (ORTs). There are no science operations before landing. The primary science and instrument operations teams involved in day-to-day instrument operations will be co-located at JPL immediately prior to, and during, the Surface mission. The operations teams are described below:

The Project Management Team will be responsible for management of Europa Lander mission operations. The Project Manager is supported during mission operations by the Project Scientist, the Project Science Group, the Science and Payload Manager, the Public Engagement Office, the Mission Assurance Manager and Staff, System Engineering and Configuration Management Staff, the Deputy Project Manager for Operations, the Mission Manager (MM), and the PIs. The MM will coordinate with each operational element to ensure effective planning and safe execution of each mission phase and to ensure that appropriate practices are applied throughout the mission.

The Mission Operations Team (MOPS) will perform five main functions: (1) real-time command and control of the flight system, (2) planning and testing of integrated command sequences, (3) mission level post-event assessment, trending, and performance prediction, (4) mission planning, and (5) mission testing. Certified flight controllers in the MSA will perform all forward link operations, monitor system health, and respond to limits and alarms using contingency operations procedures. Should instrument behavior indicate a health problem, the PI's instrument expert will be consulted, and/or instrument safing contingency plans will be executed at the earliest opportunity. The fundamental responsibility for instrument health rests with the PI.

The Spacecraft Team (S/C) will provide the subsystem expertise to support real-time operations, subsystem post-event assessment, trending, and performance prediction and planning for spacecraft events as needed during all mission phases. Subsystem experts will come from the institution that provides the capability. The S/C Team will augment the MOPS team's real-time assessment and contingency support capabilities.

The Navigation Team (Nav) will deliver the Cruise Vehicle to the proper Europa Deorbit, Descent, and Landing conditions. These conditions are influenced by the launch and selected landing site, as well as other engineering considerations.

The Science Operations Team (SciOps) comprise the PSG and instrument teams, and will provide science data processing, instrument planning, and instrument sequence generation and validation, working closely with the MOPS. The SciOps team will perform NASA Level 0 processing of science data and distribute data products to science investigators and instrument teams. The SciOps team will ultimately integrate and deliver archival data products to the Planetary Data System (PDS). Table 6-1 illustrates the various roles within the SciOps team. The SciOps team, including instrument teams and PIs, will be co-located at the MSA at JPL for the duration of surface operations.

Table 6-1. Europa Lander Science Operations Team Roles

Role	Staffed by each Instrument Team	Responsibilities
Science Operations Working Group (SOWG) Chair		Lead the science team to a consensus for daily planning. Follow the planning and sequencing process to ensure science desires are maintained. Assist with preparing skeleton plan for next planning cycle. Lead science meetings to discuss working hypothesis and overall mission results.
Project Science Group (PSG)		Advise Project and SOWG Chairs on optimization of mission science return, use of consumables.
Science Theme Groups (STGs)		Test hypotheses, analyze data, prepare activity plans, and update strategic plans.
SOWG Documentarian		Take notes on data assessment and activity planning effort and rationale for SOWG decisions.
Principal Investigator	X	Point of contact for Project for strategic instrument issues.
Payload Element Lead (PEL)	X	Coordinate science operations associated with a specific instrument.
Payload Downlink Lead (PDL)	X	Verify and monitor the payload health and status of all expected and received data products.
Payload Uplink Lead (PUL)	X	Assist with planning in SOWG meeting; ask for clarification of SOWG intent if necessary. Build, deliver, and verify the instrument sequences that will carry out the activity plan.

The Instrument teams will provide—on a daily basis during the surface science phase—instrument command sequence development, coordination of science plans within and across instrument teams, and coordination across spacecraft teams for major activities. Instrument operations specialists within the instrument teams will provide instrument health monitoring, trending, and performance analysis. Command Sequences are developed by many teams across the Project and will be centrally integrated and tested by the MOPS team. The instrument operations teams will create sequences for each instrument based on mission and science observation plans, coordinating with other instrument teams and the Science Operations team to ensure proper distribution of resources.

Science Operations teams will perform data reduction and science analysis each day to inform tactical decision-making, and given the short duration of the mission, the instrument's analysis technique must be able to return concrete, actionable results within days. Proposals should scope Phase E staffing accordingly, as well as describe the specific features of the measurement technique and instrument design that will enable the Science Operations team to support rapid tactical decision-making.

Instrument teams will also provide instrument command sequences for instrument checkout, calibration, and maintenance operation between launch and landing. The instrument teams will be co-located at the MSA at JPL for these activities.

6.1.2 Software

The Europa Lander Ground Data System (GDS) includes the integrated suite of ground hardware, software, facilities, and infrastructure for the MSAs, as well as all Project ground interfaces to the DSN, PDS, Launch, and I&T locations. Major GDS software elements and their expected properties are summarized in Table 6-2. Flight software (FSW) and subsystem models will be provided to the GDS through a series of planned builds. The ground software sets will be developed and tested (including surface operations capability) prior to launch; the Project will also have a software maintenance plan and post-launch development plan to support post-launch ops testing and training as needed, commensurate with the needs of mission operations of this duration.

Table 6-2. Europa Lander Ground Data System Software List

Team	Software Element	Major Functions (including Fault Management)
MOPS (Including Spacecraft)	Telemetry and command	Telemetry and command for mission operations and mission simulations
	Mission and sequence planning	Observation optimization and sequence generation for mission operations
	Data handling and assessment	Data storage, catalog, retrieval and archiving; Data trending, and other utilities
	S/C planning and analysis	Spacecraft subsystem performance modeling for assessment, trending, and prediction. Arm and Sampling system operations will have dedicated team during surface operations.
Nav	Mission design and navigation	Orbit determination, maneuver design, generation of navigation products, trajectory optimization
SciOps	Data pipeline	Science data and housekeeping processing; generate raw and calibrated data products
	Data access	Distribute data products
	Uplink tools	Planning analysis and visualization; instrument sequence generation
	Data analysis	Analysis and visualization of science data products

Spacecraft simulation functionality is important to an efficient spacecraft operations system, for team training, software testing, command load verification, and anomaly resolution. A spacecraft/instrument-emulating workstation testset (WSTS) combining S/C FSW with GDS software (primarily telemetry and command) and environmental simulation will be developed for spacecraft simulation. Ideally, instrument flight software, if applicable, will be built in a way such that it can be incorporated into the testset for a more complete flight system simulation.

With additional external connection capability, it is possible the WSTS could be used to support instrument development in the following manner. After establishing payload data flow interface requirements and design, WSTS deliveries will allow for early-simulated interface tests prior to running software acceptance tests. After software acceptance testing, the instrument FSW will be further tested with the WSTS during payload integration and testing, as well as during mission operations. The Project will control WSTS access for these activities. As a project capability, appropriate functionality could be made available to domestic instrument teams/developers. Similar availability to non-US instrument teams could be proposed through a TAA.

6.1.3 Facilities

The GDS will include all hardware, software, data links, and facilities used to conduct tests and operations, generate and uplink commands, and receive, process, and disseminate telemetry and test data.

The Europa Lander MSA will be provided at JPL. This area will accommodate all elements of the flight team required to ensure spacecraft health and safety and most of the JPL-supplied engineering systems and subsystems team members. These facilities will be established prior to the start of operational readiness testing, and most of the test operations will be supported from this MSA. Full capabilities for surface operations may wait until surface ORT’s, which are primarily post-Launch.

The JPL MSA will be sized to accommodate Key Science Flight Team elements for selected periods, including the full duration of surface operations. PIs should specify their needs for this MSA space.

All communications among the MSA, Nav team, and DSN Operations Center at JPL will occur over the NASA Integrated Services Network (NISN), as is the case for current interplanetary missions. All communications among the MSAs that are staffed by different segments of the ground operations team will occur via secured network connections.

The GDS architecture, as well as significant software, will primarily be derived from ground systems currently used for planetary mission operations. Architectural features will permit seamless and real-time connectivity between the MSA and the launch facilities, to allow for remote (off-site) monitoring and MOPS team control during scheduled tests. The MSA will have backup external data and voice communications lines to permit operations to continue if service from the primary lines is disrupted, as well as backup power sources. Altogether, these features will ensure that Europa Lander operations will continue uninterrupted during all mission phases.

The MOPS and S/C team software sets described in Table 6-2 will be deployed to the MSA. All MSA computing hardware will be provided by the Project.

The MSA will be protected by multiple firewalls. Access protocols will use encryption and require authentication before access. All connections to NISN will adhere to NASA and institution security regulations.

It is expected that each PI will develop and maintain instrument-specific tools and communicate hardware needs in order to support instrument operations while co-located in the JPL MSA. This facility will provide for instrument command generation, retrieval of essential instrument telemetry data for instrument status, performance and health assessment, retrieval of instrument science data, participation in the operations science planning process, and a means for rapidly validating and distributing science data and preparing science data for archiving. The instrument software and network configuration shall meet Project-specified security, interface, and performance requirements. The Project specifications for interfaces and performance will be developed in Phases A and B.

6.2 Operations Timelines and Data Flow

This section describes the general attributes of science operations with respect to the operational timelines for the mission phases and data flow between the MOS/GDS and the Europa Lander spacecraft. Aspects of the following functions specific to particular mission events or scenarios are described in more detail in Section 5.

6.2.1 Operations for Launch through Deorbit, Descent, and Landing (DDL)

The Europa Lander MOS/GDS will be capable of supporting science instrument periodic maintenance and calibration activities from Launch through the approach for DDL, although the availability and timing of the calibration activities will be highly constrained by mission priorities. Key periods relevant for instruments include: instrument commissioning, cruise calibrations, and calibrations during approach and Jovian tour. Instrument periodic maintenance activities can include limited updates to both the instrument flight software or instrument onboard parameters. Due to the brevity of the surface phase, instrument checkouts, calibrations, and maintenance must be designed and planned to ensure that instruments are fully prepared for science operations—including verification of major functionality and internal interfaces, and completion of any necessary outgassing—<u>before</u> DDL. The SciOps and MOPS teams will plan, sequence, and execute the instrument calibration activities using the planning and sequencing process as outlined in Section 6.2.2.2. Proposals should indicate the description, frequency and timing of calibration, checkout, and maintenance activities required prior to DDL to prepare for surface operations.

Before launch and during cruise, several surface system operational readiness tests (ORT) will be performed, including at least one off-nominal surface ORT. Staffing and schedule timelines will be based on surface operations.

6.2.2 Operations for Surface Phase

Refer to Section 5.5.1 for Europa Lander surface operations key terminology.

6.2.2.1 Spacecraft Data Flow Context

For the DTE mission as described in Section 5, most of the sampling activities will nominally be executed during Earth-in-view periods, where a rapid ground cycle is possible. To maximize the productivity of these periods, the rapid ground cycle is limited to actions that require key decisions best made by the ground team and able to use pre-planned actions that can be finalized quickly for uplink, as shown in Figure 6-2. These quick responses include specific Go/No decisions for the next sample, or changes to a limited pre-determined set of parameters.

Longer strategic assessments, decisions and development of plans and activities can occur during the longer Earth-out-of-view periods. Just before Earth sets, an end-of-Europan day data downlink is possible where a bulk of the day's sampling data can be transmitted to Earth. This could feed into the strategic planning process, where Science teams can review and analyze the sample results, and then convene to discuss and decide on any new plans for the next sample(s). Once a new plan is decided, a process to generate the new uplink products is kicked off as part of Sequence Development shown in Figure 6-3.

The Europa Lander spacecraft will have the capability to receive data using any DSN 34- or 70-meter station, and expects to be able to send data using DSN station configurations, including the 70m station, during surface phase to maximize the data return for the short mission duration. The total expected daily data return volume is defined in Section 6.4.1 and is contingent on many constraints, including: DSN availability and geometry, landing site, energy capacity, and Lander onboard data storage capability.

6.2.2.2 Ground Planning Cycle

The MOPS and SciOps teams will translate PSG priorities and requests into sequences that command the Lander and payload. While the duration of the ground planning cycle is to be determined, operations processes are intended to facilitate rapid turnaround during surface tactical operations; thus, they will use a template-based approach based on a small set of repeated science scenarios to develop the science sequences. The ground planning cycle consists of (in order): telemetry processing, quicklook product generation, and the planning and sequencing process. The planning and sequencing process includes science activity planning and command load generation and validation. The entire ground operations cycle is expected to be between ~ 6 (for rapid ground cycle) to 20+ (for strategic planning and development) hours in duration. Figures 6-3a and 6-3b show examples of the Science planning and sequence flow for a cycle that supports a fuller replan while Earth is out of view, and a shorter rapid ground cycle for when Earth is in view. Additional processing, analysis, and trending of telemetry data products is expected to occur outside the ground planning cycle; teams should plan for 24/7 staffing to ensure maximum utility of the surface operations period.

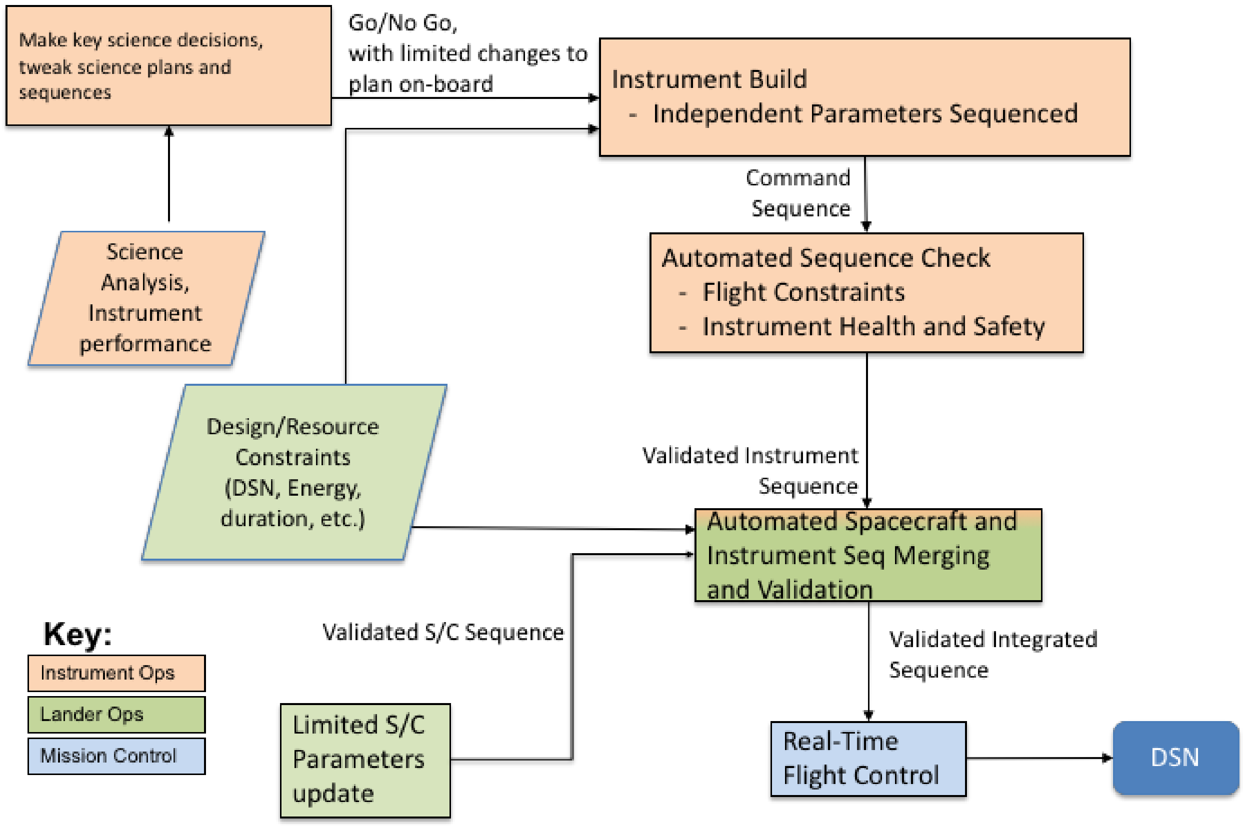

Figure 6-2. Example of Rapid Science Decisions and Sequencing Flow during Earth-in-View periods

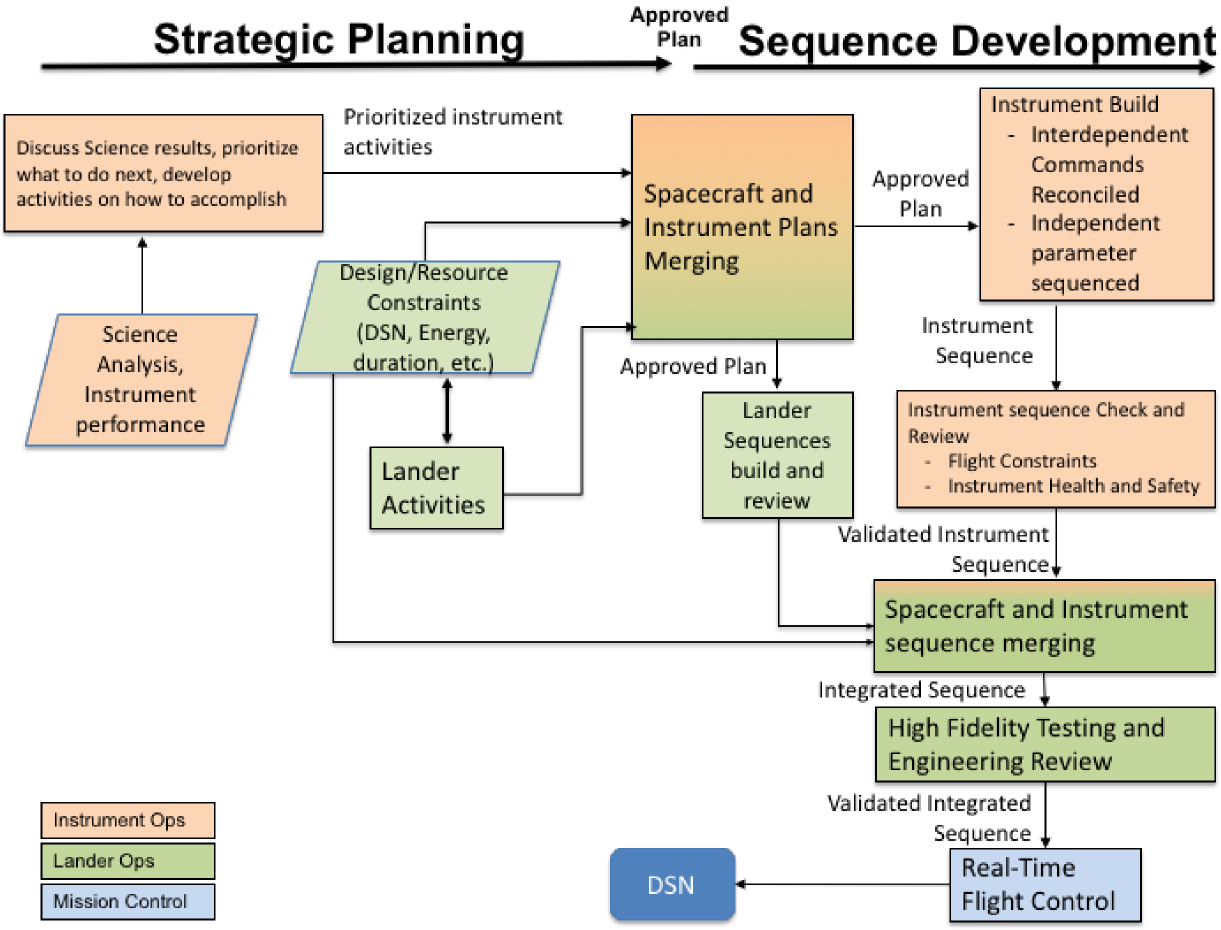

Figure 6-3. Example of Strategic Science Planning and Sequencing Flow during Earth-out-of-View periods

The Lander will have limited resources (including power, duration, onboard data storage, CPU, etc.) that require both flight- and ground-based management. The SciOps team, working closely with MOPS, will provide the integrated science plan to the instrument teams for instrument command generation. These instrument sequence products will then be delivered to MOPS for integration into the overall command load.

Per Section 6.1.2, spacecraft analysis tools and models will be made available to instrument teams early to ensure consistent assessment of system behavior for instrument operations development and observation planning. Processes and applicable tools will be provided in the MSA at JPL for rapid command planning, and for science coordination and synergy. The required capabilities will be demonstrated in pre-launch system testing and surface ORTs during Cruise.

A standard interface to the sequencing and planning system will be used for all of the instruments and science disciplines.

6.2.2.3 Telemetry Data Reception and Processing

The MSA will receive raw packets of return link data in the form of Consultative Committee for Space Data Systems (CCSDS) File Delivery Protocol (CFDP) formatted files. The return link prioritization of the various instrument data files, as well as relevant spacecraft engineering data files necessary for science data reconstruction, will be accomplished in conjunction with the science planning and sequencing process described in Section 6.2.2.2, and tied to the overall data return link prioritization to be performed by the MOPS team. Requests for particular spacecraft engineering data will be counted against the respective instrument's return link data allocation. Once the instrument and engineering data packets are extracted from the return-linked files, automated processes will be used to process this data into the NASA Level 0 products, i.e., reconstructed, unprocessed instrument and payload data at full resolution, with any and all communications artifacts (e.g., synchronization frames, communications headers, duplicate data) removed. These products are subsequently delivered to the instrument teams for their higher-level science data processing. Typically, some of the processing functions are implemented in conjunction with a JPL specialized data/image processing team or other third-party processing facility, and some are separately implemented by the instrument team.

6.3 Data Processing Plan

The MSA will ensure that instrument telemetry data, spacecraft, ephemeris, instrument, NASA Level 0 processed science data, and associated information needed to process relevant data sets into higher-level science data products and archival data records are made available in a timely manner to the instrument teams. The instrument teams and, as appropriate, the Participating and/or Interdisciplinary Scientists will generate, validate, and release data products, including the timely distribution of data to the MSA and the full Europa Lander science team. The PI, in conjunction with the instrument teams, will also ensure the transfer to the PDS of all data archives with associated files and information relevant to their instruments or investigations.

The Europa Lander Project will develop a science data-sharing and archive plan with the expected high-level strategy for timely preparation and distribution of three types of data products:

1. **Collaborative Data Products:** The Data Plan specifies policies and procedures for sharing of quick-look and processed instrument data among members of the full Europa Lander science team, referred to as Collaborative Data Products.
2. **Archival Data Products:** The Data Plan specifies policies and procedures for timely generation, validation, and delivery of data products from the Europa Lander instrument teams to the PDS in complete, well-documented, permanent archives, referred to as Archival Data Products. The archives will contain raw and reduced data, documentation, and any necessary algorithms or software to process the data to higher-level reduced data products. The Archival Data Products will be delivered to the PDS six months after receipt of science and associated calibration data.
3. **Public Data Products:** The Data Plan specifies policies and procedures for distributing data and information to the general public and the other communities served by NASA in a timely fashion (e.g., within hours) during the time period of the proposed Europa Lander surface mission, referred to as Public Data Products.

Refer to the PEA for more specifics on data product information.

6.4 Monitoring and Responses to Anomalies

Europa Lander flight system and instrument health and performance will be monitored during pre-sequenced return link passes. Red alarm / out-of-limit conditions will trigger an automated notification process. The MOPS team will staff spacecraft forward link activities as required, with the support of on-call engineers when needed. Following the completion of a return link pass, the instrument teams and spacecraft ops teams will be expected to assess the state of the instruments and spacecraft and conduct ongoing performance and trend analysis on varying timescales, depending on the criticality and amount of activities executing on-board. Aside from automated notification, the MOPS team may require more than 2 hours to gather data and begin assessment. This may happen more rapidly, but only in the most severe circumstances. Due to round-trip light time constraints, anomaly response will not be in real time, but will use the next available scheduled uplink contact as the first opportunity for action. The flight system will be designed to remain in a safe state, continuing contingency operations as it is able, without contact from the ground for several days. It is recommended that instruments be designed to "fail operational," that is, be able to automatically resume science operations after faults. During cruise, staffed operational interaction among MOS/GDS teams will nominally be during local prime shift hours, with exceptions for selected operations and anomaly response operations. During surface operations, however, the MOS/GDS will be staffed for 24/7 operations to maximize utility during the short mission duration.

6.5 Instrument Team Responsibilities for MOS/GDS Support/Training/Testing

Training activities are required to maintain personnel skill levels and to prepare for mission operations. Relevant MOS/GDS Integration and Test (I&T) activities include: activity planning, command product generation, flight and ground system hardware and software updates and testing, operations rehearsals and Operation Readiness Tests (ORTs). These activities validate procedures and prepare the teams for upcoming critical events. During MOS/GDS I&T, missions typically conduct ORTs and other test and training activities for launch, for the first major maneuver, and for any mission critical event that could potentially cause a loss of mission. During Cruise, several surface ORTs and other test and training activities will be conducted to cover nominal and off-nominal surface operations scenarios. After JOI, surface operations training taking place over a 12-24 month period, in addition to (and in parallel with) discrete ORT activities, is planned in order to ensure the entire surface operations team—including science and instrument personnel—will be prepared to meet the surface operations timeline and able to take full advantage of the short surface mission duration (planned to be 20 Earth days). Figure 6-4 shows a notional ORT schedule, each taking 2-4 days in duration. The instrument teams will need to adequately staff and support each of these testing activities throughout the mission lifecycle.

In addition, instrument behavior descriptions and data definition are needed for common areas of the GDS (those dealing with all instruments and subsystems). It is expected that the instrument PI will participate with the GDS system engineer in the definition of these topics. This support includes the following:

- The PI will define instrument telemetry and data products including detailed descriptions of telemetry content and format for all instrument telemetry to support real-time health and safety decommutation, processing, and display; as well as engineering data record (EDR) processing. JPL will provide the XML schemas and definitions to be used by the PI.
- The PI will define instrument behavior for modeling of instrument activities, describing the intent of the science activity and identifying key spacecraft resources required to support the activity; this will include duration, power, data volume, and other key resources (i.e., use of the arm, etc.). Instrument personnel will work with the Project activity definition engineer.
- The PI will define the instrument spacecraft-level commands that are used to build instrument sequences, in collaboration with the Project system engineers. These commands will be used by the instrument team payload uplink leads (PUL) in operations to build and deliver

instrument sequences. These commands are defined using the JPL-provided command schemas and XML definitions.

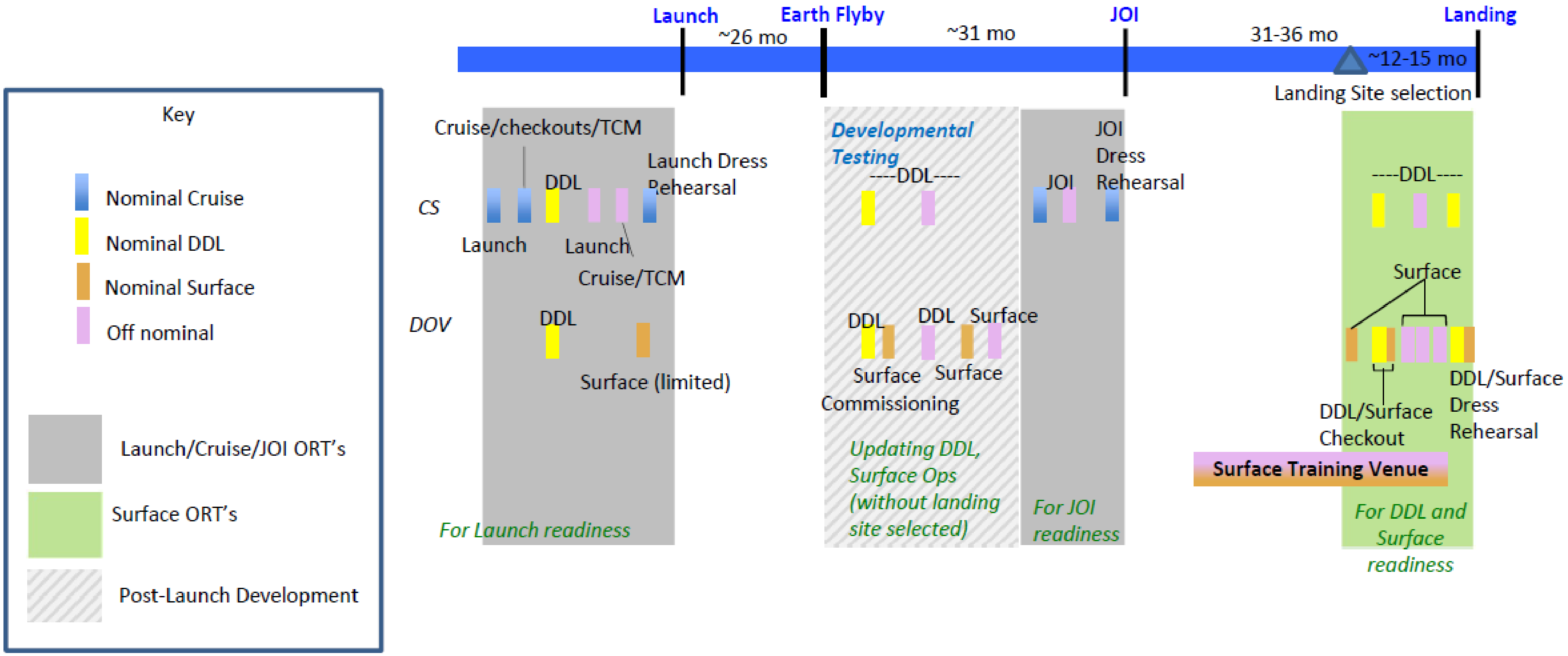

Figure 6-4. Notional Operations Readiness Test Schedule

7 ENVIRONMENTAL FACTORS

The Europa Lander Environmental Requirements Document (ERD; D-97633) specifies the Europa Lander environmental design and verification requirements. The Europa Lander ERD contains an environmental verification matrix applicable for the system, subsystem, and assembly levels and specifies the verification activities (tests, analyses, and/or inspections) to demonstrate hardware compatibility with the design requirements. The document specifically covers required environmental tests, environmental test policies, and environmental design requirements and verification levels for the following environments: handling and ground operation, launch, structural loads, dynamic loads, thermal considerations, electromagnetic compatibility (EMC), spacecraft charging, electrostatic discharging, meteoroid environment, and radiation environment. The sections below describe some of the key environments of concern for the Europa Lander. Additional details can be found in the ERD.

7.1 Radiation Environment

The Jovian-trapped radiation environment represents a uniquely challenging risk to mission performance and lifetime. Based on the current mission design trajectories and the GIRE-2p Jovian radiation model, the Lander will experience a total ionizing dose (TID) of ~1.7 Mrad, primarily from electrons, behind 100 mil Al (Si equivalent).

The local Lander radiation environment is mitigated with a combination of hardened technology and shielding. To attenuate the expected Lander dose, most Lander and payload electronics are housed in a radiation vault similar to that used on Juno and planned for Europa Clipper. Shielding inherent to the Instrument design is augmented by neighboring hardware and the surrounding Lander vault to decrease the expected TID to 150 krad (Si) or less. All electronics within the vault must be rated to 300 krad in order to maintain a radiation design factor of two (RDF = 2) to account for modeling and environmental uncertainties. Any instrument within the vault with part(s) not compliant to 300 krad (Si) will need to include appropriate additional local shielding in the instrument design. Local spot shielding shall be sized with an RDF=3. Additional shielding should be included in the mass estimate of the instrument and counted against its mass allocation.

No radiation shielding will be provided by the Project to meet the same requirement of 150 krad (Si) for instruments with electronics and sensors outside the vault at designated locations. Any additional mass required for shielding or for openings in shield boxes to make scientific observations (e.g., a camera shutter) should be included in the mass of the instrument. For instruments outside the vault, see section 4.7 of the Environmental Requirements Document for a specification of the radiation environment.

Europa Lander mission instruments should be designed to withstand the harsh radiation environment expected for the mission. Radiation effects to be included for design consideration are the life-limiting TID, Displacement Damage Dose (DDD) effects, and transients. Both TID and DDD effects produce long-term permanent degradation in instrument detector performance characteristics and other electronics. In addition, transient radiation effects are produced when an ionizing particle traverses the active detector volume and creates spurious charges. The magnitude and distribution of transient noises within a detector array requires careful attention. Refer to the Europa Lander ERD for more detail on the radiation environment for the Europa Lander mission.

In addition, instrument providers are expected to use parts and materials identified from the Preferred Parts and Material List (PPML).

Instruments will provide the resources (workforce and software) to assist in the spacecraft radiation transport analysis by delivering at specified dates the latest 3-D CAD models of the instrument in the appropriate format (See Table 9-2 for schedule).

For more information about single event effects requirements, please refer to the EEE Parts Program Requirements (D-97629).

7.2 Solid Particles

The solid particle environments include micrometeoroids, dust/particulates, and ice grains. The Jovian solid particle environment is not anticipated to be appreciable for the planned mission design. During the landing, thruster exhaust may excite ice, salt, or other particles on the surface which then have a potential to impact the Lander. Any instrumentation exposed during landing should protect against potential particle impacts (e.g., deployable covers). For additional details, see the Europa Lander ERD (D-97633).

7.3 Electrostatic Charging

The entire Europa Lander flight system will encounter the Jovian radiation and plasma environment and therefore is subject to both surface and internal charging and discharge events. Surface charging is affected largely by the external plasma environment, whereas internal charging is caused by energetic particles.

With internal charging in the Jovian radiation environment, energetic particles will penetrate into materials and deposit their charge. Over time, a charge can build up on floating conductors and on dielectrics. If the charge is not removed through an electrical bleed path, a discharge may occur. The Europa Lander Project will develop a set of guidelines for how to minimize the size of potential discharges through shielding and material selection as well as how to minimize the negative impact on hardware through robustness.

7.4 Contamination Control

Contamination levels are controlled to enable science investigations conducted by possible contact with the surface of Europa, including those with organic and/or biosignature detection, and optical imaging for engineering and/or science purposes. Additional requirements, or the identification of limitations on specific contaminant compounds, may be imposed after instrument selection, but prior to PDR. Science investigation approaches that minimize adverse contamination sensitivity or reduce contamination control requirements at the instrument and flight system level are strongly encouraged.

Instrument and spacecraft contamination sources produce particulate and molecular contamination deposits. Both particulate and molecular contamination deposits can be of an organic or inorganic nature. Organic contamination deposits can impact the science return of biosignature detection instruments and introduce significant risks to mission objectives.

Organic contaminants can further interact with space environments (e.g., ultraviolet radiation, atomic oxygen, planetary atmospheres, planetary plume emissions) which can produce photofixation, and polymerization (causing contaminant deposits to remain fixed to sensitive surfaces), and degradation of optical properties (e.g., solar absorbance, emittance, scatter). These combined effects can be a significant source of degradation to science instruments and spacecraft systems, and directly impact mission success.

Materials outgassing, thruster plumes and venting are the predominant sources of molecular contamination in instruments and the flight system. Both molecular and particulate contamination is generated during System Integration & Testing (SI&T). Particulate contamination can also be generated through degradation of materials (mechanical or due to interactions of materials with the space environment).

It is the responsibility of the proposer to deliver a complete characterization of hardware contamination sources (molecular and particulates) and contamination sensitivities and to deliver the hardware clean (from molecular and particulate contamination) and prepared for integration with the spacecraft.

Proposers will be required to provide the following information:

1. Whether the proposed instrument is sensitive to contamination (particulate and/or molecular).
2. If the instrument is sensitive to contamination, specify the limits (particulate and/or molecular).
3. Characterization of all instrument contamination sources (particulate and molecular) for each operational mode of the instrument. Contamination sources include materials outgassing (requiring identification of non-metallic materials, chemical composition, location of usage/geometry, vacuum exposed surface area, operating temperature data, ASTM E1559 outgassing rate data, vacuum baking/processing data), particulates, and outgassing venting paths.

The baseline cleanliness and contamination control requirements for the Europa Lander will assume a contamination control program implemented for the flight system, engineering systems, and science payloads which is designed to be similar to the Europa Clipper Mission as defined in the Europa Lander Contamination Control Plan (CCP) to be provided by the project.

Contamination control will be an ongoing process, addressed throughout the mission lifetime by:

- Definition of contamination requirements and budget
- Development of Project Contamination Control Plan and Requirements
- Characterization of flight system and instrument contamination sources (e.g., materials outgassing rate testing)
- Control of materials outgassing induced contamination (e.g., materials selection, thermal-vacuum baking specifications, preferential outgassing venting paths, utilization of molecular absorbers)
- Control of particulate contamination (e.g., process sampling, inspections, NVR/particulate measurements and monitoring, cleaning)
- Development of a contamination model and analyses to verify that contamination-sensitive surfaces do not exceed their EOM contamination requirements (including molecular and particulate transport models for cruise phase, surface phase, etc.)
- Initial delivery of clean science instrument hardware
- Initial delivery of clean spacecraft hardware
- Operational methods that apply standard best-practice contamination control techniques.

The contamination control program is designed to control molecular and particulate contamination of contamination-sensitive instruments and systems during all phases of the mission. The contamination control program will address:

- Materials outgassing induced contamination
- Particulate contamination
- Thruster plume induced contamination

7.4.1 Materials Outgassing Induced Contamination

Materials outgassing requirements will be defined in the Europa Lander Contamination Control Plan (CCP). Materials driving induced contamination levels may require testing per ASTM E1559, Method B (custom testing).

Silicone materials have a high potential for causing reflectance loss on optical surfaces and property changes on thermal control surfaces. The use of any silicone materials will be assessed for cross-contamination with contamination-sensitive surfaces (instrument or spacecraft). All silicone-based material shall be identified and submitted to the JPL Project contamination control engineer (CCE) for approval prior to use.

Instruments will be integrated with the spacecraft in a Class 100,000 (ISO 8) or better facility. Instrument components such as MLI, electronics, cabling, and other designated instrument hardware will require thermal vacuum bake-out to remove out-gassing contaminants prior to instrument integration. Instrument design should preclude lubricated hardware from contaminating adjacent Lander hardware (e.g., other instruments) and any critical internal items (e.g., lenses, mirrors, detectors). Requirements for dry nitrogen purge, more stringent clean-room facilities, or other special integration procedures should be identified. Instrument providers will need to assess contamination susceptibility of their hardware and support development of the approach documented in the CCP to reduce risk of degraded performance.

7.4.2 Particulate Contamination

Particulate contamination may include both biogenic and abiogenic sources. Particulate cleanliness levels for all hardware will be based on IEST-STD-CC1246E and defined in the Europa Lander CCP.

No material shall shed or otherwise generate particulate debris during normal operation and the range of expected hardware temperatures as a result of vibration, shock, incidental contact, or aging. This requirement will be verified by review of the design drawings by the applicable Materials and Process or Contamination Control engineering review.

7.4.3 Thruster Plume-Induced Contamination

During descent, the Descent Stage (DS) thrusters will use hydrazine as a combustive fuel. The DS has two sets of four thrusters, one set canted 5 degrees off nadir and the other set canted 30 degrees. During the terminal descent and sky crane phases of DDL (10-30m above the surface), the DS will only use the engines that are canted 30 degrees off nadir to minimize contamination. The descent engine thrusters will operate to a minimum altitude of 10 m over the Europa surface above the landing site. At this altitude the Lander should touch down, the bridle will be cut, and the DS will fly away from the landing site.

Though thruster plume induced contamination will be minimized as much as possible, hydrazine exhaust will necessarily deposit on the surface near the landing site. All scientific instruments should expect that hydrazine exhaust constituents will be present on the surface as a result of landing. The primary exhaust constituents of combusted hydrazine are ammonia, nitrogen, and hydrogen with smaller amounts (<1% by weight) of water, carbon dioxide, aniline, iron, chloride, and unburnt hydrazine. The maximum allowable contaminants for Ultra Pure™ hydrazine (the type that will be utilized by the DS) are shown in Table 7-1. It should be noted that these are maximum values; analysis of ammonia, water vapor and hydrazine levels following a hot fire test of the Phoenix Mars Lander thrusters suggests that the contaminant levels in high purity grade hydrazine may be considerably lower than these specifications.

The condensation temperatures in vacuum of hydrogen and nitrogen are 4 K and 26 K, respectively. Ammonia has a condensation temperature of 101 K. Initial expectations are that, of the primary exhaust constituents, ammonia will remain largely present on Europa's surface near the Lander. All of the lesser constituents are assumed to remain present as well.

Emissions from the hydrazine thruster catalyst beds will also contribute to contamination of the landing site. These emissions are composed of iridium coated aluminum oxide particles. The baseline operation of the DS will use throttled thrusters. It is anticipated that the total amount of catalyst bed emissions will be limited to a fraction of a microgram during the entire descent.

Table 7-1. Composition of Ultra Pure™ hydrazine.

Component (% by Weight)	Ultra-Pure ™ grade
Hydrazine, min	99.5
Water, max	0.5
Particulate, max	1.0 (a)
Ammonia	0.3 (b)
Aniline, max	Free (c)
Carbon dioxide, max	0.003
Chloride, max	0.0005
Iron, max	0.0004
Non-volatile Residue, max	0.001
Other Carbonaceous non-volatile material (d), max	0.005

(a) mg/l
(b) Max
(c) Not detectable at detection limits of all specified methods
Total as Unsymmetrical dimethyl Hydrazine (UDMH), monomethyl hydrazine (MMH), and alcohol

7.4.4 Sample Transfer Chain and Instrument Contamination Control

Instruments proposing to analyze in situ samples should consider the entire sample transfer chain as part of the instrument CCP. The sample transfer chain includes any surfaces that may come into contact with the in situ sample itself, as well as any products generated during the analysis of that sample (e.g., gases produced via heating). Any in situ sample will be exposed to a certain level of contamination due to sample acquisition and handling prior to delivery of the sample to the instrument. Therefore, instrument proposers should include in the CC requirements budget a sub-allocation for any in situ samples due to the sample handling chain. Sample transfer chain CC will be defined in coordination with the instruments.

The instrument providers shall each submit an instrument CCP for approval by the Project Contamination Control Engineer prior to IPDR. The plan shall describe, at a minimum, the following:

- Susceptibility to degradation from internally and externally generated contamination.
- Contamination budgets for contamination-sensitive surfaces for each mission phase.
- Valid and verifiable end-of-life (EOL) cleanliness values and how these values were derived.
- Predicted contribution of self-contamination to the EOL cleanliness values.
- Methodology and frequency of monitoring, cleaning, inspection, and certification.
- Acceptable cleaning solvents (grade, non-volatile residue [NVR]) and cleaning materials (type of materials, acceptable extractable residue, and particulate generation).
- Sequence of activities.
- Environment definition and traceability.
- Thermal vacuum test contamination criteria using temperature-controlled quartz crystal microbalance (TQCM) data, if required.
- Contamination violation reporting and assessment effects.
- Packaging material criteria, cleanliness levels, and procedures.
- Transportation and storage controls for ensuring contamination protection and monitoring.
- Cleanroom garments, controls, and monitoring.
- Purge gas purity and monitoring, if applicable. Hardware that requires a purge shall identify the gas, gas purity, and flow rate in the appropriate CCP. Periods of allowable purge interruption and test requirements for the purge gas supply and delivery system shall also be specified.
- Confirmation that the instrument can perform the Europa mission in the predicted contamination environment (i.e., ground processing, launch, landing, surface operations).
- Instrument-specific requirements to preserve cleanliness during ground processing (post-delivery through launch).
- Identification of instrument-specific contamination controls that shall be implemented during system integration to preserve cleanliness during ground processing (post-delivery through launch). This may include bags, covers, purges, controlled environments, etc.
- Compliance with outgassing requirements.
- Implementation and verification of the facilities (cleanrooms) specified in the CCP.
- Mandatory inspection points for instrument cleanliness verification prior to system delivery.
- Mandatory inspection points for ground support equipment cleanliness verification prior to delivery.

8 SAFETY AND MISSION ASSURANCE

This section discusses Safety and Mission Assurance (SMA) requirements for the Europa Lander mission concept with the purpose of ensuring reliable, high-quality hardware. Instrument teams are encouraged to meet these requirements through the use of their own existing plans and processes wherever possible.

8.1 Mission Assurance Requirements

Instrument teams will be required to provide SMA plans as defined by the documents specified in Table 1-1. PIs are responsible for producing and maintaining records, including test and analysis reports and other controlled records, sufficient to demonstrate compliance with Project MA requirements. Project Mission Assurance will make this data available for review. Supporting MA documents listed in Table 1-1 provide additional details describing Project MA requirements.

8.2 Reliability Assurance Requirements

Instrument teams will be required to provide the following reliability analyses for flight instruments (See Table 9-2 for delivery schedule):

- Fault tree analysis (FTA) of mechanical and electromechanical assemblies
- Worst case analysis (WCA), including the electrical interfaces between flight equipment provided by different cognizant design agencies. Worst-case analysis should include effects of radiation specified in the Europa Lander ERD (D-97633).
- Single event effects (SEE) analysis
- Interface failure modes and effects criticality analysis (FMECA)
- Functional FMECA
- Parts stress analysis (PSA)
- Thermal stress analysis to support the PSA and system thermal modeling
- Structural stress analysis
- Ground support equipment failure modes and effects analysis (GSE FMEA)
- Power supply and transient analysis
- Parameter trend analysis for limited life or consumable items critical to mission success
- Sneak circuit analysis

Each analysis will be reviewed by an independent, Project-approved reviewer. All design analyses shall be maintained to reflect the hardware configuration as the flight design evolves through the lifecycle.

Reliability assurance needs, including required reliability and design analyses, are described in the Europa Lander Reliability Assurance Plan (D-97630).

8.3 Problem/Failure Anomaly Reporting (PFR)

Closed-loop problem/failure anomaly reporting (PFR) is needed for critical hardware and software. Critical hardware is defined as flight, flight spare, EM hardware that could be used as flight or spare, inherited hardware and software, and GSE that interfaces with flight hardware.

Formal PFR activity should be initiated at the start of testing of the completed flight instrument at the instrument provider’s facility. Reporting will cover hardware and software anomalies, as well as any incident with associated equipment or procedures that call safety or quality into question. PFRs should be written and forwarded promptly to the Payload Office for review. The Project will concur on closures and approve PFRs that carry residual mission risk. Closure review of pre-delivery PFRs will be included in the Instrument Delivery Review (IDR).

"Developmental" PFRs (DPFRs) will be used for non-qualification EM hardware, and are recommended for brassboard or prototype hardware. The review and approval cycle for DP/FRs will be abridged compared to formal PFR review and approval.

8.4 Electrical, Electronic, and Electromechanical Parts

Flight electrical, electronic, and electromechanical parts shall meet the requirements described in Europa Lander Parts Program Requirements document (D-97629).

8.5 Preferred Materials and Processes Selection List

The Project has developed a Preferred Materials and Processes Selection List (D-92600). This document will be updated as new information becomes available over the spacecraft development cycle. The PMPSL represents "preferred" materials and processes but does not imply that all materials and processes listed therein are appropriate for any application. The use of standard materials and processes given in the PMPSL may still require the use of a material usage agreement in some applications. Use of materials and processes not on this list may require a Project approval or materials usage agreement granted by the Project. Instrument teams will be responsible for qualification of the material and should account for cost of their selected materials.

8.6 Hardware Quality Assurance

Hardware quality assurance requirements will be described in the Europa Lander Quality Assurance Plan document (D-97632). This document will reference the following workmanship standards:

- NASA-STD-8739.1A, Workmanship Standard for Polymeric Application on Electronic Assemblies, dated March 4, 2008, with Change 2 dated March 29, 2011
- J-STD-001ES, Joint Industry Standard, Space Applications Electronic Hardware Addendum to J-STD-001 E Requirements for Soldered Electrical and Electronic Assemblies, dated December 2010 (Chapter 10 of IPC J-STD-001ES does not apply)
- NASA-STD-8739.4, Crimping, Interconnecting Cables, Harnesses, and Wiring, dated February 9, 1998, with Change 6, dated March 29, 2011
- NASA-STD-8739.5, Fiber optics Terminations, Cable Assemblies, and Installation, dated February 9, 1998, with Change 2, dated March 29, 2011
- ANSI/ESD S.20.20, Protection of Electrical and Electronic Parts, Assemblies, and Equipment (Excluding Electrically Initiated Explosive Devices), dated March 1, 2007
- IPC-6011 Class 3/A: Generic Performance Specification for Printed Wiring Boards, dated July 1996
- IPC-6012B with Amendment 1, Class 3/A: Qualification and Performance Specification for Rigid Printed Wiring Boards, dated January, 2007
- IPC-6013B Class 3, Qualification and Performance Specification for Flexible Printed Boards, dated January, 2009

8.7 Software Quality Assurance

Software Quality Assurance (SQA) assures the instrument provider's software products and processes meet JPL standards and requirements. Project SQA requirements are detailed in the Europa Lander Quality Assurance Plan document (D-97632). These requirements are applicable to all Class B (Non-Human Space Rated) and Class C (Mission Support) software. The instrument provider's proposal will include a SQA function consistent with these requirements. The instrument provider will also include the capability to perform a software/safety hazard analysis.

SQA functions will include review and concurrence with the software identification, classification, and safety criticality assessment. SQA will review the instrument software's process tailoring record. SQA assures that the instrument provider's Software Management Plan (SMP) is compliant with JPL software development requirements. Instrument software is subject to review, analysis, verification, and assurance of bi-directional requirements traceability. SQA will verify the contents of software work product deliveries in accordance with the contract and applicable requirements. SQA will also perform periodic product and process audits throughout the life cycle. Prior to delivery, instrument software shall be formally reviewed and certified to be complete and acceptable.

JPL SQA will provide oversight of the functions described above when performed by instrument provider's SQA.

The instrument development team is expected to follow a rigorous process in the development or acquisition of any instrument software product, including flight, ground, and ground support equipment software. This process is expected to be compliant with a Project Software Development Requirements (SDR) to be released after instrument selection. The SDR is a set of best practices, activities and products designed to improve the likelihood of a successful product. One key aspect is preparing a software development plan, which in addition to structure, schedule, and delivery plans, also establishes the detailed processes and practices that will be followed by the instrument software development team. Detailed practices include configuration management, software reviews, software V&V planning, software requirements management, as wells as specific rules regarding design, implementation, and unit test. Five standard software documents that are expected (see Table 9-2 for schedule): Software Development Plan, Software Requirements Document, Software Design Document, Software Integration and Test Plans, and Software Users Manual. Additionally, instrument teams are expected to provide development artifacts at SRCR to support assessment of product and process quality compliance.

8.8 Systems Safety Approach

All organizations furnishing instruments, related ground support equipment, and operations shall provide assurance that such equipment will not jeopardize people, equipment, habitats, or prime mission accomplishments. All instrument teams shall comply with the systems safety requirements contained in the Europa Lander Project Safety Plan (D-97631). This document will reference the following NASA standards:

NASA-STD 8719.9	Standard for Lifting Devices and Equipment
NASA-STD 8719.12	Safety Standard for Explosives, Propellants and Pyrotechnics
NASA-STD 8719.13	Software Safety Standard
NASA-STD 8719.24	NASA Expendable Launch Vehicle Payload Safety Requirements

Deviations from the Europa Lander Project Safety Plan should be reviewed and approved by the Europa Lander Systems Safety Engineer.

Instrument teams shall supply pertinent payload safety information to the Europa Lander Project Safety Engineer for incorporation into the Missile System Pre-Launch Safety Package (MSPSP) and payload safety reviews at the launch site. All documentation regarding payload safety information, including detailed information on hazardous elements such as radioactive sources, lasers, hazardous mechanical elements, pyrotechnic devices, etc., shall be submitted by the instrument team to support submission by the Europa Lander project to launch safety and National Environmental Policy Act (NEPA) reviews.

Software safety/hazard analyses and audits will be conducted by the Project to ensure compliance with NASA/JPL software safety policies, to verify that output values and/or timing do not place the system in a hazardous state, and to ensure that the software responds appropriately under hardware failure scenarios.

9 SCIENCE PAYLOAD MANAGEMENT

9.1 Management Approach

This section describes the roles and responsibilities of key science and payload management personnel of the Europa Lander Project in support of the selection, successful development, and conduct of instrument investigation teams for the Europa Lander mission.

The Europa Lander Project payload management approach supports the Principal Investigators (PIs), associated Co-Investigators (Co-Is), and instrument teams. As such, the Project will provide

- Funds in a timely manner at the negotiated levels
- Engineering guidance and advice to instrument teams
- A management framework for developing flight instruments
- Technical and programmatic decisions as required to successfully accommodate the selected payload on the spacecraft
- Expert review panels to critique progress and plans

To provide effective support, PIs will be required to provide documentation of their investigation plans and schedules with periodic updates on instrument development progress, financial status including Earned Value Management documentation, and technical performance.

Each PI is encouraged to utilize techniques that have proven successful on previous space missions, and the following specific principles apply:

- The instrument team should develop an Experiment Implementation Plan (EIP) and an Experiment Operations Plan (EOP).
- Consistent with applicable NASA management instructions, the PIs bear the primary responsibility for ensuring that the instruments are designed and developed in a manner that will meet the objectives of the selected instruments and the Europa Lander mission as a whole. The PIs should demonstrate to Project Management that this responsibility has been fulfilled and that the detailed design is compatible with performance requirements.
- Project design control will focus on the interfaces of the instrument with the spacecraft system and MOS, including launch vehicle safety, system-level test, and mission design, as well as those critical risk areas of instrument development that are specific to Europa Lander (e.g., design approaches for radiation shielding and planetary protection).
- The Project shares with the PIs the responsibility for ensuring that the mission assurance aspects of the instrument development effort are consistent with both the mission duration and the expected environments. Consequently, the Project will assess the development effort to verify that the mission assurance aspects of the Project-approved Mission Assurance Plan and the EIP are being properly implemented.

Each PI will be fully responsible for ensuring that their selected investigations are implemented within the resource allocation except as modified by written Project approval.

9.2 Project Roles and Responsibilities

9.2.1 Project Organization

The Jet Propulsion Laboratory (JPL) is assigned management of the Europa Lander Project. JPL will provide Project Management and Project Science leadership. A development phase organization chart is shown in Figure 9-1. The Payload Office will manage the science instruments.

As the Project matures and the operations phase nears, a different organization will be identified for the operations phase of the mission.

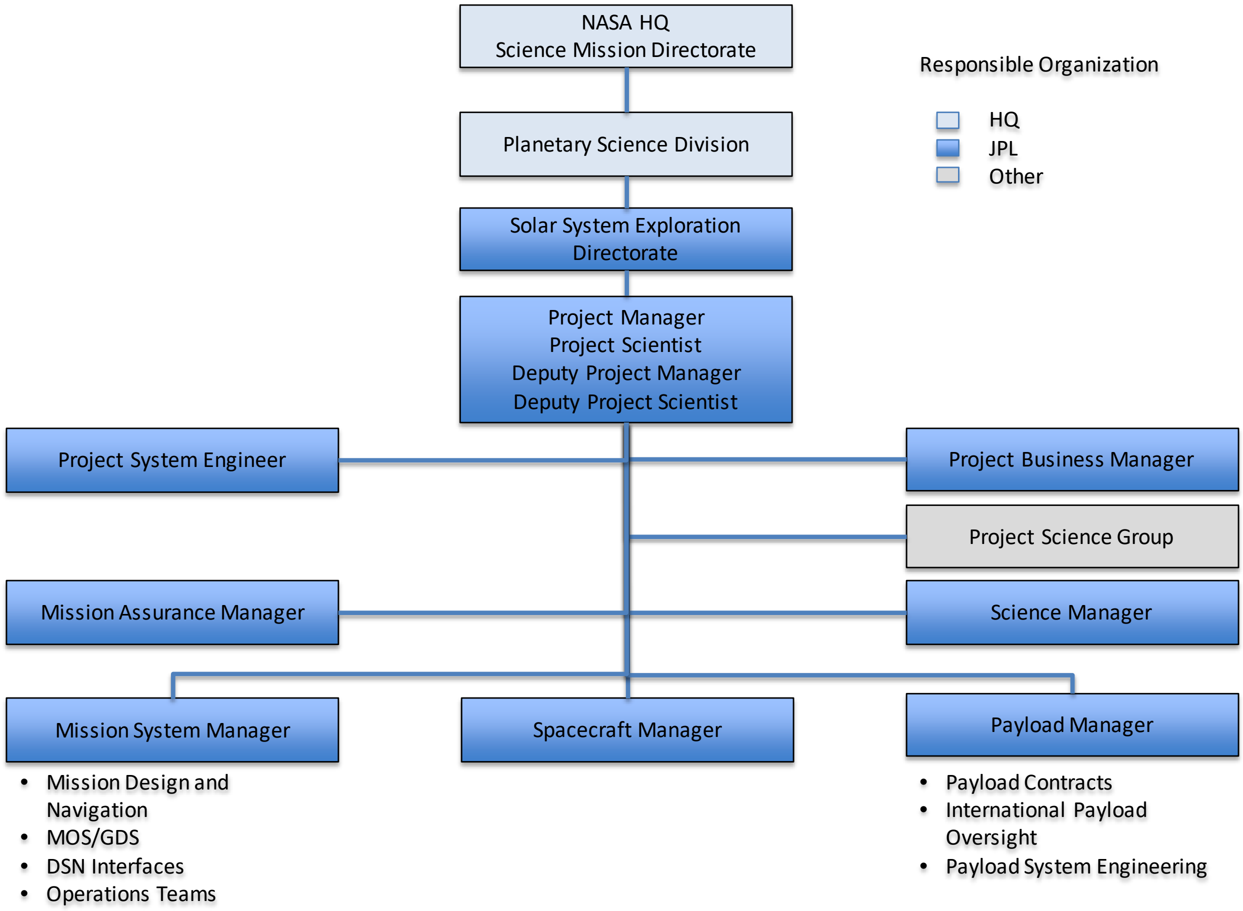

Figure 9-1. Europa Lander Project Development Phase Organization Chart

9.2.2 Project Manager Responsibilities

The Project Manager (PM) is responsible and accountable for all aspects of mission success and maintains management oversight of Project activities including ensuring timely detection and correction of problems. As relevant to the instrument procurement, the PM will be responsible for ensuring that the prospects for scientific return are maximized within Project constraints, oversees all systems trades, coordinates and oversees the identification of systems engineering design issues, and leads the planning and integration of technical and operational approaches for the Project. The PM reports to the NASA Program Executive to ensure technical and programmatic compliance for the mission.

9.2.3 Project Scientist Responsibilities

The Project Scientist (PS) is responsible for the scientific integrity and overall scientific success of the Project. The PS represents science interests to the Project, NASA, the broader science community, and the general public. The PS is a peer of the Project Manager in all matters impacting science and in science-engineering design trades. The PS reports to the JPL Director and the NASA Program Scientist and is co-located with the Project Manager as a member of the Project staff.

As relevant to instrument procurement, the PS is the liaison between the science investigators and the Project. The PS is responsible for ensuring that the Level 1 science requirements are met, including ensuring the scientific investigations are properly supported within the resource allocation to achieve the optimal scientific outcome and that the investigators properly carry out their responsibilities. The PS will work with PIs, Co-Is, and any participating and/or interdisciplinary scientists to, if necessary, descope investigations as required to stay within resources. The PS supports and cooperates with the NASA Program Scientist in carrying out their joint roles and responsibilities. Investigation PIs for each instrument will support the Project Scientist.

9.2.4 Payload Manager Responsibilities

The Payload Manager will report to the Project Manager (PM) and will oversee and coordinate the individual investigation development programs to ensure timely instrument hardware, software, and documentation deliveries that are compliant with the requirements, policies, and resources of the Project. The Payload Manager will be responsible for providing the primary interface and point of contact between the payload developer(s) and Project including the contract technical management of the individual JPL-issued instrument contracts.

Specifically, the Payload Manager will:

1. Develop and negotiate work scope and funding vehicles, using work agreements, subcontracts, or memoranda of understanding as appropriate, for each selected instrument through delivery, integration with the spacecraft, and launch +30 days.
2. Be responsible for ensuring that all instruments are compatible with the Europa Lander design, the interfaces are properly defined and controlled, and that sufficient spacecraft resources are allocated.
3. Provide the overall technical and managerial leadership for the design, development, manufacture, and delivery of each instrument, in cooperation with the instrument teams.
4. Plan, direct, monitor and control instrument resources, schedule, risk, and performance commitments in fulfilling the science objectives.
5. Establish and approve instrument functional requirements, in cooperation with the Europa Lander Science Manager and Investigation PIs, for each instrument.
6. Establish and approve interface agreements between each instrument team and the Europa Lander Project.
7. Ensure that instrument teams apply a mission assurance program that is consistent with the Project mission assurance requirements at and across the interface to the spacecraft.
8. Provide technical representatives and advisors from instrument system engineering, planetary protection, radiation effects, mission assurance, mission operations design, and other selected specialists as needed.
9. Provide for the support of the integration of each instrument flight unit with the spacecraft.
10. Ensure the quality, accuracy, integrity, and timeliness of each instrument model including its technical documentation, reports, and other correspondence.

A payload system engineering lead and one or more payload accommodation/instrument system engineers will support the Payload Manager.

9.2.5 Science Manager Responsibilities

The Science Manager (SM) ensures that the science requirements are implemented such that the mission science objectives will be met. The SM works integrally with the Project Scientist, Deputy Project Scientist(s), the Project Science Group (PSG), and all Project technical elements to ensure the overall mission science requirements are negotiated, documented, articulated, and implemented. The SM serves as the custodian of Project science policies and priorities, coordinating them with the Project Scientist. The SM also develops and documents plans to meet the science instruments in terms of Europa target priorities, science operations concept development, science data management plan, data archiving plan, and science scenario development. The SM develops a PSG-approved science operations and planning process for the Interplanetary and Europa Science phases of the mission. During Phase E (launch +30 days), the SM will serve as the contract technical manager for all science contracts, including PIs and any participating and/or interdisciplinary scientists. A science system engineer will support the Science Manager.

9.3 Principal Investigator and Science Team Roles and Responsibilities

9.3.1 Principal Investigator Responsibilities

The PI is responsible for all aspects of the selected PI instrument and investigation. These include the instrument design and development, fabrication, test and calibration, and delivery of flight hardware, software, and associated support equipment within Project schedule and payload resources. The PI is also responsible for planning and supporting the instrument operation. The PI will oversee their selected instrument and investigation, while participating in joint data analysis efforts with other members of the full Europa Lander science team. Key functions of the PI include, but are not limited to, the following:

1. Be the instrument team’s primary point of contact with other Project elements regarding instrument and investigation requirements, schedules, and funds. Represent the instrument team in relevant Project reviews and meetings.
2. Generate and maintain documentation regarding the instrument.
3. Ensure delivery and operation of an instrument able to achieve the investigation science objectives within mission resources, assuming nominal spacecraft operation.
4. Participate in PSG meetings and associated working groups.
5. Support mission operations planning and execution.
6. Conduct the instrument’s operation consistent with the Mission Plan and the Project resources.
7. Ensure that data reduction, analysis, reporting, and archiving of investigation results meet with the highest scientific standards and completeness, consistent with budgetary and other recognized constraints.

9.3.2 Co-Investigator Responsibilities

As part of a selected investigation, the Co-Is are responsible for assisting in the planning and operational support of instrument hardware, cooperative data analysis within the PSG, and the generation and archiving of data products. Co-Is are full and equal members of the PSG and are expected to attend PSG meetings. Key functions of Co-Is include, but are not limited to, the following:

1. Aid in ensuring delivery and operation of an instrument able to achieve the investigation science objectives within mission resources, assuming nominal spacecraft operation.

2. Support mission operations planning and execution, including operations test and training.
3. Prepare for data analysis and timely collaborative, archival, and public data product generation and archiving.
4. Ensure that the cooperative data reduction, analysis, reporting, and archiving of the results meet with the highest scientific standards and completeness, consistent with budgetary and other recognized constraints.

9.3.3 Project Science Group Responsibilities

The PSG consists of the full Europa Lander Science Team (Project Scientist, Deputy Project Scientist(s), principal investigators, co-investigators, and participating and/or interdisciplinary scientists). The Project Scientist sets scientific requirements and priorities on behalf of the PSG, which the PS chairs in conjunction with the NASA Headquarters Program Scientist, who is an ex-officio member. The PSG helps to optimize mission science return and efficiency and prioritize science requirements in accordance with the governing and unified Europa Lander Science Team operating "Rules of the Road," defining how activities and data are managed as a team. The rules will apply uniformly to the full Europa Lander Science Team.

9.4 U.S. Export Control Compliance

U.S. proposers must comply with all U.S. Export Control regulations for exchange of technical data with foreign entities. To that end, investigators proposing joint instrument developments with non-U.S. partners (either U.S.-led or foreign-led) will prepare and complete Technical Assistance Agreements (TAAs) with any other non-U.S. entities with whom they will be sharing technical data. Such agreements shall be signed and in place before exchange of technical data between such partners is possible. Therefore, in order to meet the Europa Lander development schedule, U.S. proposers should plan the necessary legal work during proposal preparation.

9.5 Schedule

Approval of a Project schedule is pending, however for planning purposes, the Europa Lander pre-Project team has been working to an earliest possible launch date. While the year of launch may change, proposers should assume the following.

Table 9-1 illustrates the notional Europa Lander key Project milestones.

Table 9-1. Project Milestones

Project Milestone	Baseline Date
Mission Concept Review	June, 2017
Project Preliminary Design Review	December, 2021
Project Critical Design Review	March, 2023
Project System Integration Review	June, 2024
Pre-Ship Review	January, 2026
Operations Readiness Review	September, 2026
Mission Readiness Review	October 2026
Launch	November, 2026

Phase A starts following a Mission Concept Review (MCR) and ends with a combined System Requirements Review (SRR) and Mission Definition Review (MDR). The Preliminary Design Review (PDR) marks the transition into detailed design; Critical Design Review (CDR) marks the transition into flight hardware build culminating in the System Integration Review (SIR) at the start of ATLO. The integrated flight system will be shipped to KSC following the Pre-Ship Review (PSR). The Operations Readiness Review (ORR) and Mission Readiness Review (MRR) will be held just prior to launch. The definition of these reviews can be found in NPR 7120.5E. These schedule milestones are subject to change.

9.5.1 Project Reviews

The PIs (or their designees) are expected to attend and support, as needed, design and management reviews for the Project, spacecraft, and MOS systems, as well as occasional informal reviews scheduled by the Project.

9.5.2 Instrument Level Reviews

Instrument-specific reviews will be held for all investigations. Table 9-1 and the following paragraphs provide a summary of the scheduled instrument reviews. In general, the instrument design reviews precede the Europa Lander Project design reviews and, except as negotiated, will be held at the PI's home institution.

The Payload Manager, with input from the PI, Project Scientist, and other Project management, will select and convene a payload review board for each of the instrument milestone reviews. The members of the board will participate throughout the investigation lifecycle to provide continuity of review. The Payload Manager may adjust or augment the review board as needed per the necessary technical or programmatic experts. Review board membership will include Project science and technical management representatives, as well as members from the PI's and major subcontractor organizations.

PIs should conduct appropriate technical peer reviews prior to milestone reviews to validate approach and design decisions. These peer reviews will be summarized at the milestone reviews.

9.5.2.1 Kickoff

The Kickoff meeting will formally integrate selected flight instrument PIs, instrument managers, and systems engineers with the Europa Lander Project team. It is anticipated that this meeting will immediately follow PSG Meeting 1, which will formally introduce the full Europa Lander Science Team including PIs, Co-Is, and any participating and/or interdisciplinary scientists.

9.5.2.2 Instrument Accommodation Review (IAR)

Shortly after instrument selection, each instrument team will begin preliminary design activities and prepare to support the Instrument Accommodation Review (IAR), which will be convened by the Payload Manager and held at a central location. The purpose of the IAR is to establish the instrument's compatibility with the spacecraft, to formulate a firm commitment with the instrument team for the Project-supplied resources and interfaces (including, but not limited to, mass, power, volume, fields of view, and environments), including evaluation of interactions among instruments to ensure equitable sharing of spacecraft resources. Results will feed into the Project SRR.

All inherited items or designs will require a detailed review because of the unique radiation environment and planetary protection requirements. This review should be accomplished by the SRR and may occur during the IAR.

9.5.2.3 Instrument Preliminary Design Review (I-PDR)

The I-PDR evaluates the readiness of the instrument to proceed with detailed design. It assesses the compliance of the preliminary design with the applicable requirements. It also assesses the maturity of the subsystem planning. The completed Instrument Requirements Document (IRD) and preliminary ICDs are presented. Findings will be reported at the Project PDR.

9.5.2.4 Instrument Critical Design Review (I-CDR) and Instrument V&V Review

The I-CDR establishes the completeness of required design analysis, test, and establishment of radiation design margin. The I-CDR evaluates the readiness of the instrument to proceed with implementation of the instrument. It assesses the compliance of the detailed design with the applicable requirements and the subsystem planning done for the implementation. Findings will be presented at the Project CDR.

Three months later, the I-CDR will be followed by a separate Instrument Verification and Validation (V&V) Review where the details of the Instrument V&V plan will be reviewed, including the inputs from the instruments to the Incompressible Test List and the Test-As-You-Fly-Exceptions-List.

9.5.2.5 Instrument Delivery Review (IDR)

The IDR evaluates the readiness of hardware, software, and support equipment for delivery to system assembly, integration, and test and includes the engineering model (EM), flight model (FM), spares, and ground support equipment (GSE). Topics include results of verification of compliance with IRD and ICD, results of environmental testing, and completeness of the End Item Data Package (EIDP), waivers, open failure reports, and closed but unverified failure reports. Closure and risk rating of pre-delivery problem/failure reports will also be reviewed. Hardware Requirements Certification Review (HRCR) and Software Requirements Certification Review (SRCR) are reviews associated with the IDR. These reviews are the final review of hardware and software documentation, analysis, compliance, and open item closeout process after hardware has been delivered for integration.

9.5.3 Instrument Level Periodic Meetings

9.5.3.1 Monthly Management Reviews (MMR)

Monthly Management Reviews of programmatic, financial, and technical status will be hosted at either the PI's or the instrument hardware developer's home site and attended by the Project either in person or via teleconference and/or videoconference. The intent of the MMRs is to provide timely insight into instrument progress with minimal impact on work effort. Major topics to be addressed include:

- Progress versus plan during past reporting period, and plans for next period
- Problems, risks, concerns, and mitigation plans
- Schedule status and variance from baseline
- Cost, including comparison of actual and planned cost and an explanation of any variances
- Procurement and subcontract status
- Financial reports (e.g., NASA Form 533, monthly and quarterly)

9.5.3.2 Instrument Interface Meetings (IIM)

To foster close interactions between the instrument team and spacecraft system technical personnel, a series of meetings will be scheduled to work out interface issues and document the design in the ICDs. The Europa Lander Project will host the initial IIM meeting. Some IIMs that follow can become "virtual" meetings, with the instrument teams supporting by a combination of telecons, videoconferences, and e-mails.

These are not formal reviews, but rather technical interface meetings among the instrument team engineers, the spacecraft engineers, and the payload system engineers. The initial focus will be on hardware and software interface issues, but will transition into resource sub-allocation discussions and operational strategies as the launch date approaches.

9.5.4 Instrument Deliverables to Project

Section 4.1 describes the deliverables required from the Instrument provider to the Project.

9.5.5 Project Deliverables to Instruments

After the Instrument PDR, the Project will deliver the following items on the schedule depicted in Table 9-1.

Suitcase simulator: the suitcase simulator, built by the Project, will simulate the Lander electrical and data interfaces so the instrument may test their units prior to delivery to the Project.

Engineering model and flight model connectors and platinum resistance thermometers (PRTs): the Project will provide all connectors that are part of the interface between the instrument and the Lander flight system. In addition, the Project will provide all PRTs to be used by an instrument, and the Project will catalog all such PRTs.

Intra-instrument cables: any cable that penetrates the vault wall will be manufactured by the Project in design collaboration with the instrument team.

9.5.6 Cost and Schedule Reports

A NASA-funded PI and instrument team should initiate cost accounts according to an agreed upon Work Breakdown Structure (WBS) and WBS Dictionary.

At the Project SRR, a most-probable cost estimate for each instrument, supported by model-derived and grass root methodologies, will be developed. This estimate will include a risk list, risk retirement criteria, and date. An instrument schedule and baseline budget time phased by month will be necessary at I-PDR.

A NASA-funded PI will provide input to the Payload Manager to support the Europa Lander Project's earned value reporting, which will begin after the I-PDR. Any individual instrument team whose contract value exceeds $20M should independently implement an acceptable earned value reporting system from the inception of the contract. If events call for a revision of the negotiated baseline cost plan, the Project will ask for it contractually.

Instrument teams led by PIs from other participating countries will provide financial reporting as called for and/or deemed appropriate by their national funding agency.

Table 9-2. Instrument Reviews and Deliverables

Major Reviews and Deliverables	Timing
Instrument Reviews	
Instrument Kickoff	1 month after selection
Instrument Accommodation Review (IAR)	8 months after selection
Instrument Preliminary Design Review (I-PDR)	16 months after IAR
Instrument Critical Design Review (I-CDR)	14 months after I-PDR
Instrument Delivery Review (IDR)	19 months after I-CDR; 1 month prior to instrument delivery
Instrument Operations Readiness Review (ORR)	Launch - 150 d
Instrument Hardware Deliverables	
Sampling Interface Testbed Hardware	I-PDR + 120 d
Instrument Electronics Breadboard to JPL	I-PDR + 9 mo
Instrument Engineering Model Delivery	I-CDR + 120 d
Flight Model Delivery	IDR + 30 d
Project Hardware Deliverables to Instrument	
Suitcase Spacecraft Simulator to Instrument	I-PDR + 3 mo
EM Electrical Connectors, PRTs to Instrument	I-PDR + 9 mo
Flight Electrical Connectors, PRTs to Instrument	I-PDR + 11 mo
Intra-Instrument Cables to Instrument	I-PDR + 11 mo

Table 9-3. List of Instrument Documentation and Software Deliverables

Instrument Deliverables	Draft	Preliminary	Final	Update
Integration, Test & Verification				
Verification & Validation Plan	IAR - 30 d		I-PDR - 30 d	
Calibration Plan		I-PDR - 30 d	I-CDR - 30 d	IDR - 30 d
Instrument Test & Verification Plan		I-PDR - 90 d	I-CDR - 30 d	
Telemetry Calibration Data		I-CDR - 30 d	IDR - 30 d	
Handling & Operation Requirements		I-CDR - 30 d	IDR - 90 d	
Instrument User Manual		I-CDR - 30 d	IDR - 30 d	
Test Procedures, & Test, Verification, & Calibration Results		I-CDR - 30 d	IDR - 30 d	
Instrument Input to the Project Incompressible Test List and Test-As-You-Fly-Exceptions-List		I-CDR - 30 d	IDR – 30 d	
Baseline Telemetry Calibration Data			IDR	
HRCR/SRCR/SECR, EM			I-CDR + 120 d	
Unit History Log Books			IDR - 30 d	
Instrument Environmental & Functional Testing			IDR - 120 d	
HRCR/SRCR/SECR, FM			IDR + 30 d	
Management Documentation	Draft	Preliminary	Final	Update
Experiment Implementation Plan (EIP)		IAR - 30 d	I-PDR - 30 d	
Information & Configuration Management Plan (ICMP)		IAR - 30 d	I-PDR - 30 d	
WBS & Dictionary			IAR - 30 d	
End Item Data Package			IDR - 30 d	
Experiment Operation Plan (EOP)		I-PDR - 30 d	I-CDR - 30 d	L - 180 d
Mission Assurance Documentation	Draft	Preliminary	Final	Update
Safety Plan	IAR - 30 d		I-PDR - 30 d	
Mission Assurance Plan (MAP)		IAR - 30 d	I-PDR - 30 d	
Materials & Processes Control Plan (MPCP) & Data		I-PDR - 30 d	I-CDR - 30 d	
Reliability Data & Analyses		I-PDR - 30 d	I-CDR - 30 d	
MOS/GDS	Draft	Preliminary	Final	Update
MOS/GDS Requirements		I-PDR - 30 d	I-CDR - 30 d	
Command Dictionary		I-PDR - 30 d	I-CDR - 30 d	IDR - 30 d
Telemetry Dictionary		I-PDR - 30 d	I-CDR - 30 d	IDR - 30 d
Activity Dictionary		I-PDR - 30 d	I-CDR - 30 d	IDR - 30 d
Data Distribution & Archive Plan		I-PDR - 30 d	I-CDR - 30 d	
Model Deliveries	Draft	Preliminary	Final	Update
Analytic Thermal & Structural Models (S/W)			I-CDR - 30 d	
CAD Models	IAR - 30 d	I-PDR - 30 d	I-CDR - 30 d	IDR - 30 d
Radiation Transport Model	IAR - 30 d	I-PDR - 30 d	I-CDR - 30 d	IDR - 30 d
Structural Models & Analyses	IAR - 30 d	I-PDR - 30 d	I-CDR - 30 d	IDR - 30 d

Thermal Models & Analyses	IAR - 30 d	I-PDR - 30 d	I-CDR - 30 d	IDR - 30 d

Software Deliveries	Draft	Preliminary	Final	Update
Software Development Plan		IAR - 30 d	I-PDR - 30 d	
Software Requirements Document & Software Design Document		I-PDR - 30 d	I-CDR - 30 d	
Instrument Software Simulator Specification			I-PDR + 9 mo	
Ground Software & Documentation		I-CDR - 30 d	L - 180 d	
Software I&T Plans		I-CDR - 30 d	IDR - 90 d	
Software Users Manual		I-CDR + 120 d	IDR - 90 d	

System Engineering Documentation	Draft	Preliminary	Final	Update
Functional Requirements Document (FRD)		IAR - 30 d	I-PDR - 30 d	
Instrument Requirements Document (IRD)		IAR - 30 d	I-PDR - 30 d	
Interface Control Document (ICD)	IAR - 30 d	I-PDR - 30 d	I-CDR - 30 d	
Contamination Control Plan		I-PDR - 30 d	I-CDR - 30 d	
Planetary Protection Implementation Plan (PPIP)		I-PDR - 30 d	I-CDR - 30 d	IDR - 30 d

10 INSTRUMENT ACCOMODATION WORKSHEET

Instrument ___________________________ PI _______________________________________

Fill out the worksheet below completely. You may: (i) specify the requested instrument characteristic in the worksheet; (ii) provide the information in attached sheet(s); or (iii) reference the location(s) in your proposal where the information is already stated. Specify any non-compliance in detail. Sections or lines that are not applicable may be deleted to save space, but please do not renumber them. Note that the resources worksheet (10.1) is also required.

Item	Description	Proposer Response (include reference to section(s) in proposal where possible)	Non-Compliance (State 'none' or specify in detail, add pages as needed)
0 General Questions			
0.1	Is the proposed instrument compatible with the spacecraft, trajectories, mission scenario concepts, and launch vehicle types described in Section 2 & 3?	Yes/No (add pages or reference location in proposal if non-compliant)	
0.2	Are there any landing sites that are incompatible with the proposed instrument?	Yes/No (add pages or reference location in proposal if non-compliant)	
1 Mass			
1.1	Provide MEL.	Reference location in proposal	
1.2	Provide the following mass values in kg. Include both Current Best Estimate (CBE) and contingency.		
1.2.1	Total mass.		
1.2.2	Mass in vault.		
1.2.3	Mass outside vault.		
1.2.4	Local radiation shielding mass within instrument		
2 Power			
2.1	Provide average and peak power per instrument mode, and a profile of mode vs. time for each operational scenario.	Provide in Resources Worksheet (10.1)	
3 Volume			
3.1	Provide dimensioned drawing(s) of unit(s), including sample transfer location, if applicable	Provide as attached sheet(s) or reference location in proposal	
3.2	Describe margin on all volumes.		
4 Mounting			
4.1	Provide mounting footprint dimensions.		
4.2	State preferred sensor mounting location(s) and orientation(s).		
4.3	Specify required boresight viewing direction (if applicable).		
4.4	Specify preferred radiator viewing direction (if applicable).		
4.5	Any other mounting restrictions? Describe.		
5 Electrical interfaces			
5.1	Specify requested command and telemetry data interface (high speed vs. low speed - see Section 3.9)		
5.2	List any acceptable alternative command and telemetry data interfaces.		
5.3	Specify number and type (2V vs. 5V) of power interfaces.		
5.4	Specify number of requested release circuits, if any.		
5.5	Specify number of requested analog interfaces, if any		
5.6	Specify number of input or output discrete electrical interfaces		
5.7	Provide current draw profile, including maximum current draw transient expected.	Provide as attached sheet or reference location in proposal	

Item	Description	Proposer Response (include reference to section(s) in proposal where possible)	Non-Compliance (State ‘none’ or specify in detail, add pages as needed)
5.8	Describe harness specifications (connector types, number of connectors, location of connectors, number of conductors, signal types, noise requirements, etc.).	Provide attached sheet or note in drawing	
5.9	Specify any cabling external to the vault.	Provide drawings	
6 Electromagnetic environment			
6.1	Describe grounding approach.	Reference location in proposal	
7 Thermal			
7.1	State the planned thermal interfaces to S/C (i.e., thermal block diagram depicting thermal conductivities, power dissipation, etc. for relevant instrument components to spacecraft and environment interfaces in driving thermal case(s).)	Provide as attached sheet	
7.2	Specify operating and survival temperature ranges for each sub-assembly.		
7.3	For externally mounted instruments (or instruments inside the vault with internally isolated components), describe survival heating requirements, if any.		
7.4	For internally mounted instruments, specify maximum local heat flux dissipated on vault walls.		
7.5	Will thermal maintenance for instrument survival (i.e., survival heaters) be required? Describe.		
7.6	Describe expected power dissipation to S/C across interfaces vs. power mode.		
7.7	Describe instrument temperature monitoring expected to be provided by the S/C (include number of regions).		
7.9	Any other thermal constraints? Describe.		
8 Mechanisms			
8.1	Describe any deployable port covers including geometry, motion paths, deployment mechanism and deployment plans.	Provide as attached sheet	
8.2	Specify maximum torque and torque axis caused by articulating mechanisms.		
9 Operations and resources			
9.1	Describe typical operational scenarios, including operational modes, timeline, power use, and data generation.	Provide in Resources Worksheet (10.1)	
9.2	Describe any constraints on data collection scheduling (lighting, time of day, etc.).		
9.3	List life-limiting components or consumables and associated limits.		
9.4	State on/off cycle life limit.		
9.5	Describe any operational scenarios exceeding 30 minutes that are not part of monitoring or sampling cycle.	Provide in additional resources table (see 10.1)	
9.6	Identify the instrument modes that can operate while the Flight Computer is asleep and how the instrument ensures its own health and safety when an instrument fault occurs while the spacecraft avionics are powered off.		
9.7	Describe how instrument anomalies and faults will be tolerated, detected, identified, recovered from, and/or masked and expected operation of the instrument in the presence of faults and anomalies.		
9.8	Describe how science data is protected from loss in the presence of faults or errors.		

Item	Description	Proposer Response (include reference to section(s) in proposal where possible)	Non-Compliance (State 'none' or specify in detail, add pages as needed)
9.9	Describe how instrument design prevents instrument faults from propagating/affecting the spacecraft or other instruments		
9.10	Describe how the instrument is designed for automatic/autonomous instrument activities. Also describe what state, results, or status information will be available for use by the spacecraft to construct automatic/autonomous activities at the spacecraft level		
9.11	Describe how instrument fault protection and fault tolerance attributes are verified and validated.		
10 Calibration			
10.1	Describe inflight operations calibration plans (when, how, duration, data volume) during the following phases:		
10.1.1	Cruise (if applicable).	Reference location in proposal	
10.1.2	Jovian tour (if applicable).	Reference location in proposal	
10.1.3	Describe post-landing checkouts and calibrations required prior to first science use, including necessary ground interaction.	Provide in Resources Worksheet (10.1)	
10.2	Describe calibration targets outside instrument volume, if needed (dimensions, potential location, mass, materials, etc.).	Reference location of drawing in proposal	
10.3	Any other calibration requirements? Describe.		
11 Viewing geometry (if applicable)			
11.1	Specify field of view (FOV).		
11.2	Specify field of regard (FOR).		
11.3	Any sun and/or stray light constraints? Describe.		
11.4	Any other viewing restrictions? Describe.		
12 Pointing (if applicable)			
12.1	Specify HGA-Mounted Pointing Requirements (provide 3σ, azimuth and elevation) as follows:		
12.1.1	Precision.		
12.1.2	Repeatability.		
12.1.3	Stability.		
13 Sample collection and handling (if applicable)			
13.1	Describe sample collection requirements:		
13.1.1	Minimum required sample volume.		
13.1.2	Number of samples that can be processed during the mission		
13.2	Describe sample container and interface requirements:		
13.2.1	Required sampling system interface (observation at a distance, sample delivery with container, sample delivery without container).		
13.2.2	If using observation at a distance, any required sample port cover/window material (fused silica, etc.)? Describe.		
13.2.3	If using sample delivery, any required sample container geometry, or end cap material on instrument interface side (foil seal, etc.)? Describe, including thickness.	Provide as attached sheet	
13.2.4	Describe any sample processing that will be completed by the instrument after delivery of sample.	Provide as attached sheet	
14 Data Management and compression			
14.1	Provide desired/planned compression algorithms and expected compression ratios to be done by C&DH, if any.		
14.2	Describe the flow of data from collection to delivery to the C&DH. Provide onboard data processing scenarios from raw → ready-for-downlink and associated volumes at each step (list for calibration and surface operations data separately).	Provide as attached sheet	

Item	Description	Proposer Response (include reference to section(s) in proposal where possible)	Non-Compliance (State 'none' or specify in detail, add pages as needed)
14.3	Specify maximum required data rate from instrument to C&DH vs. operating mode.		
14.4	Any internal instrument data storage volume provided? Describe.		
14.5	Describe any instrument- or investigation-unique functionality that can be hosted in C&DH/FSW to save power/mass/cost.		
15 Spacecraft (S/C)			
15.1	List all S/C services are you expecting to be provided (list here even if also identified elsewhere). These may include, but are not limited to, time-sensitive command or coordination activities, S/C time knowledge (specify time synchronization inputs – accuracy, etc.), control of survival heaters, sample delivery handoff/coordination, etc.	Provide as attached sheet	
15.5	Describe the behaviors you expect from the S/C when the instrument has a fault or error condition (e.g., power cycle instrument).		
15.6	Any other electrical expectations, thermal expectations, data expectations, control expectations, sample delivery expectations, fields of view, distance to surface or calibration targets, vibration, etc.? Describe.		
15.7	Verification and Validation (V&V)		
15.7.1	Describe how fault protection and fault tolerance attributes are verified and validated.	Reference location in proposal	
15.7.2	Will the instrument require additional post-delivery integration or V&V time beyond what is called out in Section 4.3? Describe.		
16 Contamination			
16.1	Is the instrument sensitive to particulate and/or molecular contamination during cruise, DDL and/or surface operations? Describe.	Reference location in proposal	
16.2	List contamination sources, particulate and molecular (during cruise, DDL and surface operations).	Reference location in proposal	
17 Radioactive material			
17.1	Describe any internal radiation sources (Note: RHUs are non-permissible).	Provide as attached sheet	
17.2	List any radioactive source(s) required for test and calibration activities.		
18 Deliverables			
18.1	List deliverable hardware/software articles and dates.	Provide as attached sheet or reference location in proposal	
19 Exceptions, if any, including rationale and usage			
19.1	Describe any non-compatibility with planetary protection processing (see Section 3.14).		
19.2	Describe any non-compatibility with planetary protection VHP during integration.		
19.3	Describe any non-compatibility with planetary protection alcohol-wipe cleaning (surfaces).		
19.4	Any parts or materials in vault unit not hard to 300 krad (150 krad x RDF =2) that require additional shielding? If so, specify.	Provide as attached sheet	
19.5	List any parts or materials not on the Preferred Parts and Materials List (PPML).	Provide as attached sheet	
19.6	List any ERD requirements not met. Including incompatibility with environmental tests listed in Table 4-3.	Provide as attached sheet	
19.7	Other exceptions? Describe.		
20 Special handling/operating constraints post-delivery and during environmental test			

Item	Description	Proposer Response (include reference to section(s) in proposal where possible)	Non-Compliance (State 'none' or specify in detail, add pages as needed)
20.1	Any instrument purge requirements post-delivery and/or during environmental test? Describe.		
20.2	Other special handling/operating constraints? Describe.		
20.3	System I&T		
20.3.1	Does the instrument need a GSE Remove Before Flight cover? Describe.		
20.3.2	Is there a minimum vacuum needed prior to turn-on? If so, specify torr.		
20.3.3	Is there a requirement for humidity? If so, specify in percent.		
20.3.4	Is there a purge outage duration? Describe.		
20.3.5	Are there any red tag (remove before flight) or green tag (insert before flight) items associated with the instrument? If so, specify.	Provide as attached sheet or reference location in proposal	
20.3.6	Will there be any GSE supplies with the instrument? If so, specify.		
20.3.7	Will there be any GSE that interfaces with the instrument that may be needed after delivery? If so, specify.		
20.3.8	List any support equipment needed during system I&T.		
20.3.9	Is there any reason why access to the instrument may be needed after the final planned Lander Rework Opportunity (See ATLO schedule Figure 4-1 & 4-2?		

10.1 Resources Worksheet(s)

Following the format of the examples below, provide one table per operational scenario envisioned for the instrument. Each operational scenario should span one command cycle (nominally 24 hours), indicating in the table any time that the instrument is off.

Example of a sample cycle operation

		Instrument: Smart Phone, Operation: Snap&Send					
Step	Mode	Duration	Average power	Peak power	Require CDH to be awake?	Data generation (uncompressed)	Data generation (compressed)
1	Init	60 s	2.3 W	3.0 W	Yes	0.01 Mbits/s	0.005 Mbits/s
2	Image	60 s	3.5 W	4.0 W	No	3.0 Mbits	1.5 Mbits
3	Signal find	45 s	5.0 W	7.0 W	Yes	0.01 Mbits/s	0.005 Mbits/s
4	Transmit	120 s	5.0 W	7.0 W	Yes	0.01 Mbits/s	0.005 Mbits/s
5	Off	Remainder of cycle	0.0 W	0.0 W	No	0.0	0.0
		Total time on 285 s	Total Energy 0.33 Wh	Peak power 7.0 W		Total data vol 5.25 Mbits	Compressed 2.63 Mbits

Example of a monitoring operation

		Instrument: Household Thermostat, Operation: KeepWarm					
Step	Mode	Duration	Average power	Peak power	Require CDH to be awake?	Data generation (uncompressed)	Data generation (compressed)
1	Set	120 s	2.0 W	1.0 W	Yes	0.1 Mbits/h	0.1 Mbits/h
2	Monitor	Remainder of 24 hr cycle	2.0 W	4.0 W	No	0.1 Mbits/h	0.1 Mbits/h
		Total time on 24 h	Total Energy 48 Wh	Peak power 4.0 W		Total data vol 2.4 Mbits	Compressed 2.4 Mbits

The operational scenario may be divided into steps, where the instrument switches from one mode to another (e.g., warm-up, calibration, sample analysis, data processing, data transmit, etc.). The duration estimate for each step should be worst-case (i.e., providing the longest expected time for the instrument to be on, including time for sample handling/manipulation or processing). Average and peak power should be in Watts and be the current best estimate (CBE) value, including any heating or cooling needs above that supported by the flight system. Data generation may be recorded as a volume (Mbits) or as a rate (Mbits/s or Mbits/hr), and should be given as uncompressed and compressed values.

For each operational scenario, provide the total time on and calculate the total energy and data volume based on the relevant columns (duration, average power, and data generation). Peak power is the maximum of the peak power across modes.

For one-off operational scenarios that are not part of either a monitoring or sampling cycle (e.g. instrument checkout), provide an additional resources table if the activity exceeds 30 minutes. In the case that there are no such activities, please state explicitly in the Instrument Accommodation Worksheet (line 9.5). Any calibration activities needed prior to or after sample analysis, or regular calibration of monitoring instruments, should be included as part of the corresponding science operational scenario.

These tables should include detail about the operational model both while the lander is awake and while the lander is asleep. Instruments which intend to be powered on for a duration of 1 hour or greater must be able to operate while the Lander avionics is asleep.

APPENDIX A. Acronyms

AFT	Allowable Flight Temperature
ANSI	American National Standards Institute
AO	Announcement of Opportunity
APL	Applied Physics Laboratory
ASTM	American Society for Testing and Materials
ATLO	Assembly, Test, and Launch Operations
AU	Astronomical Unit
CAD	Computer Aided Design
CBE	Current Best Estimate
CCP	Contamination Control Plan
CCPR	Contamination Control Plan and Requirements
CCSDS	Consultative Committee for Space Data Systems
C&DH	Command and Data Handling
CDR	Critical Design Review
CDS	Circuit Data Sheets
CFDP	Consultative Committee for Space Data Systems File Delivery Protocol
Co-I	Co-Investigator
COSPAR	Committee on Space Research
CPU	Central Processing Unit
CRSI	Context Remote Sensing Instrument
CS	Cruise Stage
CV	Cruise Vehicle
CY	Calendar Year
DDD	Displacement Damage Dose
DDL	Deorbit, Descent and Landing
DEM	Digital Elevation Model
DFE	Direct from Earth
DHMR	Dry Heat Microbial Reduction
DOF	Degrees of Freedom
DOS	Deorbit Stage
DOV	Deorbit Vehicle

DPFR	“Developmental” Problem/Failure Anomaly Reporting
DS	Descent Stage
DSM	Deep Space Maneuver
DSN	Deep Space Network
DTE	Direct to Earth
DTM	Digital Terrain Model
EDR	Engineering Data Record
EEE	Electrical, Electronic, and Electromechanical
EGA	Earth Gravity Assist
EGSE	Electronic Ground Support Equipment
EIDP	End Item Data Package
EIP	Electrical Integration Procedure, Experiment Implementation Plan, Experiment Implementation Plan
EM	Engineering Model
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EOL	End-of-Life
EOM	End of Mission
EOP	Experiment Operations Plan
ERD	Environmental Requirements Document
ESD	Electrostatic Discharge
ETRR	Environmental Test Readiness Review
FM	Flight Model
FMEA	Failure Modes and Effects Analysis
FMECA	Failure Modes and Effects Criticality Analysis
FOR	Field of Regard
FOV	Field of View
FRD	Functional Requirements Document
FSW	Flight Software
FTA	Fault Tree Analysis
GDS	Ground Data System
GIRE	Galileo Interim Radiation Electron
GITL	Ground-in-the-Loop

GSE	Ground Support Equipment
HEPA	High Efficiency Particulate Air
HGA	High Gain Antenna
HMR	Heat Microbial Reduction
HRCR	Hardware Requirements Certification Record
HQ	Headquarters
H/W (HW)	Hardware
I&T	Integration and Test
I/F	Interface
I-CDR	Instrument Critical Design Review
I-PDR	Instrument Preliminary Design Review
I-TRR	Instrument Test Readiness Review
IAR	Instrument Accommodation Review
ICD	Interface Control Document
ICMP	Information and Configuration Management Plan
IDR	Instrument Delivery Review
IEST-STD	Institute of Environmental Sciences and Technology Standard
IIM	Instrument Interface Meetings
IP	Intellectual Property
IPC	Institute for Printed Circuits
IR	Infrared, Inspection Report
IRAA	Instrument Requirements and Accommodation Assessment
IRD	Instrument Requirements Document
ISAD	Icy Soil Acquisition Device
ISO	International Organization for Standardization
JEO	Jupiter Europa Orbiter
JOI	Jupiter Orbit Insertion
JPL	Jet Propulsion Laboratory
KSC	Kennedy Space Center
LGA	Low Gain Antenna
L/V	Launch Vehicle
LVDS	Low Voltage Differential Signaling
M2020	Mars 2020

MA	Mission Assurance
MAP	Mission Assurance Plan
MCR	Mission Concept Review
MDR	Mission Definition Review
MEL	Master Equipment List
MEV	Maximum Expected Value
MGA	Medium Gain Antenna
MGSE	Mechanical Ground Support Equipment
MIUL	Materials Identification and Usage List
MLI	Multilayer Insulation
MM	Mission Manager
MMR	Monthly Management Review
MOPS	Mission Operations Team
MOS	Mission Operations System
MPCP	Materials and Processes Control Plan
MRO	Mars Reconnaissance Orbiter
MRR	Mission Readiness Review
MSA	Mission Support Area
MSL	Mars Science Laboratory
MSPSP	Missile System Pre-Launch Safety Package
NASA	National Aeronautics and Space Administration
Nav	Navigation Team
NEA	Non-Explosive Actuators
NEPA	National Environmental Policy Act
NISN	NASA Integrated Services Network
NPR	NASA Procedural Requirements
NVM	Non-Volatile Memory
NVR	Non-Volatile Residue
ORR	Operations Readiness Review
ORT	Operational Readiness Test
PCU	Power Conversion Unit
PDL	Payload Downlink Lead
PDMS	Project Data Management System

PDR	Preliminary Design Review
PDS	Planetary Data System
PDV	Powered Descent Vehicle
PEA	Program Element Appendix
PEL	Payload Element Lead
PETR	Post-Environmental Test Review
PFR	Problem/Failure Anomaly Reporting
PI	Principal Investigator
PIP	Project Information Package
PJR	Peri-Jove Raise
PM	Project Manager
PMPSL	Preferred Materials and Processes Selection List
PP	Planetary Protection
PPE	Planetary Protection Engineer
PPEL	Planetary Protection Equipment List
PPML	Preferred Parts and Materials List
PPIP	Planetary Protection Implementation Plan
PPO	Planetary Protection Officer
PPP	Planetary Protection Plan
PRT	Platinum Resistance Thermometer
PS	Project Scientist
PSA	Parts Stress Analysis
PSE	Project System Engineer
PSG	Project Science Group
PSR	Pre-Ship Review
PUL	Payload Uplink Lead
PWM	Pulse Width Modulation
Q#	Quarter (1, 2, 3, 4)
QA	Quality Assurance
RA	Robotic Arm
RASP	Rapid Acquisition Sampling Package
RDF	Radiation Design Factor (part radiation capability divided by expected dose at part location)

RHU	Radioisotope Heating Unit
S2M	Safe to Mate
S/C	Spacecraft, Spacecraft Team
SciOps	Science Operations Team
SDR	Software Development Requirements
SECR	Support Equipment Certification Record
SEE	Single Event Effects
SI&T	System Integration and Test
SIR	System Integration Review
SLS	Space Launch System
SM	Science Manager
SMP	Software Management Plan
SOWG	Science Operations Working Group
SPG	Single-Point Ground
SQA	Software Quality Assurance
SRCR	Software Requirements Certification Review
SRM	Solid Rocket Motor
SRR	System Requirements Review
SSPA	Solid State Power Amplifier
STB	System Testbed
STG	Science Theme Group
TAYF	Test As You Fly
TAA	Technical Assistance Agreement
TBD	to be determined
TCM	Trajectory Control Maneuver
TID	Total Ionizing Dose
TLYF	Test Like You Fly
TQCM	Temperature-controlled Quartz Crystal Microbalance
TRL	Technology Readiness Level
TRN	Terrain-Relative Navigation
TVAC	Thermal-Vacuum
UART	Universal Asynchronous Receiver/Transmitter
UV	Ultraviolet

V&V	Verification and Validation
VHP	Vapor Hydrogen Peroxide
WBS	Work Breakdown Structure
WCA	Worst Case Analysis
WSTS	Workstation Testset
XML	Extensible Markup Language

APPENDIX B. References

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